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Symposium on Coal-Modified Tar Binder for Bituminous Concrete Pavements

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Symposium on Coal-Modified Tar Binder for Bituminous Concrete Pavements

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Contents

Coal-Modified Tar Binders for Bituminous Concrete Pavements

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In Fall 1958, investigations were started by the Research Division of Curtiss-Wright Corp. at Quehanna, Pa., with a view to developing improved methods for using bituminous coals and products derived therefrom as highway construction materials. It was decided to explore the possibility of making an improved binder for bituminous pavements of the hot-mix hot-lay type by dispersing coal in distilled coal tars and coal tar oils. Previous investigations had indicated that they might also be used to advantage for the production of improved highway binders.

During the first half of 1959 a task force at Quehanna assembled and constructed suitable laboratory and pilot plant equipment; determined optimum conditions for the dispersion of coal in tars and oils; compared various coals, tars, and oils as to their suitability for the purpose; produced and analyzed experimental quantities of coal-modified tar binders; and combined them with various aggregates in hot mixes. The latter were then compared with hot mixes containing typical asphalt cements and coal-tar binders. The tests appeared to indicate that it would be possible to make hot mixes with coal-modified tar cements equal or superior to those made with usual asphalt or coal-tar binders.

After the results of the Quehanna investigations were reported, a contract was made with the Commonwealth of Kentucky to build a pilot plant at Frankfort to produce 150,000 gal of coal-modified tar binder for comparison with asphalt cements normally used in Kentucky in Class I and Class I-modified bituminous pavements. During a period of three months it produced 104 batches of binder, of which 100 batches were of the three-component type (coal, tar, and oil); two were of the two-component type (coal and tar), and two consisted only of tar (RT-12). No major difficulties were encountered in the operation of the pilot plant, and binders made in it were equal in quality to those produced at Quehanna.

From the Frankfort plant, the quantities of binder were delivered to 14 test sites in various parts of the State. At two sites, three-component binder was used in hot mix laid 2 ¾ in. thick on a tar-primed soil base (Class I-modified). At all other sites, the binder was used in 1 ½-in. Class I overlays on existing black-top pavements which for the most part had required ex-

tensive maintenance because of base failures, excessive cracking, or the development of slippery surfaces.

No major difficulties were encountered in the use of the coal-modified tar binders at any of the hot-mix plants. Also, few difficulties were experienced with their application on the test sections, though atmospheric temperatures varied over an extremely wide range. They appeared to be somewhat superior to usual asphaltic hot-mixes with respect to set-up during rolling and early traffic, but inferior with respect to fuming, especially when the temperatures of the mixes exceeded 260 F.

Immediately following completion of the Kentucky test sections laboratory investigations were resumed to make further improvements in the coal-modified tar binders, particularly as to temperature susceptibility and fuming. Inspection of some of the test sections in Spring 1960, following unusually severe winter weather, emphasized the need for better temperature susceptibilities to provide greater flexibility of the overlays at low atmospheric temperatures.

Included in the laboratory investigations, which were continued during the greater part of 1960, were comparisons of the suitability of approximately 40 different coals from various parts of the United States and foreign countries; the use of low-, medium-, and high-temperature tars as dispersing media for the coals; attempts to use oils of petroleum origin as fluxing agents; and the addition of various polymers to the coal-dispersions. Also, various types of binders were compared as to their viscosities at several temperatures and numerous methods for comparing the brittleness of different hot-mix binders at low temperatures were tried.

• IN 1955 when the Curtiss-Wright Corporation established a large Research and Development Center at Quehanna, Pa., it planned, as an aid to the local community and to the State, to investigate the possibility of finding new outlets for bituminous coal of the kind mined extensively in the area. During the next three years various possibilities were explored, but it was not until the latter part of 1958 that extensive studies along any particular line were undertaken. At that time it was decided to investigate the possibility of using bituminous coal or its derivative products as highway construction materials.

SCOPE

After discussing various possibilities with members of the U.S. Bureau of Mines, Bituminous Coal Research, Inc., of Pittsburgh, Pa., and others it was decided (a) to explore the possibility of making superior road binders by digesting (dispersing) bituminous coal in coal tar and/or coal-tar oils and (b) to direct the investigation, at least at the beginning, specifically toward the development of a coal-in-tar binder for hot-mix, hot-lay, bituminous concrete construction.

Some distilled coal tar, usually of ASTM or AASHO grades RT-11 or RT-12, is employed in hot mixes in the United States but the amount is small compared with that of asphalt cement, a residual product resulting from the distillation of petroleum. Each of these materials has certain advantages and disadvantages when used as hot-mix binders but there is need for an improved type of binder that will have all of the advantages of asphalt and coal tar but none of the disadvantages of either.

It is recognized that asphaltic binders are superior to coal-tar binders with respect to temperature susceptibility; i.e., asphaltic binders exhibit comparatively small changes in consistency with changes in temperature. Pavements made with them do not tend to become as soft at elevated atmospheric temperatures or as hard at low temperatures as pavements constructed with coal-tar binders. On the other hand, coal-tar binders adhere more strongly to most aggregates in the presence of water, suffer less alteration than asphalts on prolonged contact with water, are highly insoluble in petroleum fuels and lubricants of all kinds, and impart greater and more lasting skid resistance to pavements constructed with them. Therefore, the scope of the investigation was to be the development of a hot-mix binder for use in bituminous concrete pavements that would have low temperature susceptibility, minimum fuming during mixing and paving operations, strong adhesion to aggregates in the presence of water, maximum resistance to chemical alteration by water, minimum solubility in petroleum fuels and lubricants, and the ability to impart maximum and lasting skid resistance to bituminous concrete pavements. Furthermore, the method to be tried in the development of such an improved binder was to be the dispersion of coal in coal tar and/or coal-tar oils.

HISTORY OF COAL DIGESTION

That bituminous coal can be dispersed in high-temperature coal tars or coal-tar oils has been known for at least 40 years, and for more than 25 years coal dispersion processes have been used in the United States for making steep-roof pitches and pipeline enamels. However, a review of pertinent literature and patent references, at the start of this investigation, indicated that no serious attempt had been made, at least in the United States, to use coal digestion as a means of making a superior binder for paving mixtures of the hot-mix, hot-lay type.

The earliest record of any work of similar nature appears to be a British patent (1) issued in 1896 to E. T. Dumble, a U.S. citizen residing in Texas. He described a process for "hardening liquid or viscid bitumens, tars or asphaltums either natural or artificial" by "mixing them with bituminous coal or analogous bituminous material, and subjecting them to a temperature below the volatilizing point of the lighter oils, thereby softening and dissolving the solid bituminous material and melting it with the liquid or viscid bituminous substance." The patent does not indicate that the purpose of the invention was to make an improved hot-mix binder and it is not known whether any attempts to do so were made at that early date.

In 1902, a British patent (2) was issued to George Wilton of the Gas Light and Coke Company's Tar and Ammonia Works, London, on a process for making a pitch compound or substitute by mixing "bituminous coal dust or bitumen with tar which has been distilled or not or with tar oils, soft pitch, petroleum oils or residues and distilling the mixture or hardening or digesting the same to the required extent." No mention is made in the patent to the use of such mixtures as road materials. Several references to them as pitch compounds or substitutes indicate that they probably were intended to be used for the briquetting of coal inasmuch as that was the principal use for coal-tar pitch in England when the patent was granted.

A German patent (3) granted to Rütgerswerke Aktien-Gesellschaft, Berlin, in 1918 described a process for the "unlocking of coal and solution of the bituminous constituents of the coal characterized in that the coal is heated with high-boiling coal-tar oils at reduced, ordinary or elevated pressure to temperatures about 300 C, advantageously between 320 to 350 C whereupon the obtained solutions are submitted to distillation, if necessary with the assistance of steam." According to the patent, the soluble portions of the coal obtained in this manner, together with the high-boiling coal-tar oil used for its extraction "can be used for the asphalting of streets, for the production of roofing paper and insulating material, as well as for painting media." There does not appear to have been any substantial use in Germany of coal extracts produced in this manner for any of the uses previously mentioned including the "asphalting of streets."

During the period between 1925 and 1928, extensive investigations involving the digestion of coals with coal tars and tar oils were conducted by H. J. Rose and W. H. Hill in the research laboratories of the Koppers Company in Pittsburgh, Pa., and Kearny, N.J. A method for digesting coal in coal tar or coal-tar oils resulted from the work which differed from the German method principally with respect to digestion temperatures. Whereas Rütgerswerke purposely heated a mixture of coal and high-boiling coal-tar oil to temperatures above 300 C (572 F) and preferably between 320 and 350 C (608 and 662 F) to obtain an "unlocking" (aufschliessung) or chemical decomposition of the coal, Rose and Hill heated such mixtures "to a temperature above about 200 C (392 F) and below that at which there is any substantial chemical heat-decomposition of the pure coal substance."

The last quotation is taken from Claim 1 of a patent (4) granted to Rose and Hill (and assigned to the Koppers Company) in 1933. It made no reference to the use of coal digestion products as road making materials. Other patents (5 through 14) pertaining to the production or use of coal digestion products were granted to H. J. Rose and/or W. H. Hill and assigned to the Koppers Company but none of them claimed or described the use of coal-digestion products as binders for bituminous concrete pavements of the hot-mix, hot-lay type. Furthermore, experiments along this line were not performed by the Koppers Company as part of its extensive program, begun in 1928, for the development of commercial markets for coal-digestion products. Instead its efforts were directed mainly toward the production of improved roofing pitches and enamels, both hot and cold applied, for the protection of pipelines and steel structures against underground, underwater, and atmospheric corrosion.

The first direct references to the digestion or dispersion of coal in coal tar for the express purpose of making an improved material for road construction appear to have been contained in a British patent (15) issued in 1929 to the South Metropolitan Gas Company, Herbert Pickard, and Harold Stanier of London. The intent of the process described in the patent is perhaps best illustrated by Claim 3 which reads as follows:

> A process for making a substitute for mixtures of tar and asphaltic bitumen or asphalt used for road-making and like purposes consisting in dispersing in the tar such a proportion of coal or analogous bituminous material (not exceeding 15 percent of the final mixture) as will give at a given temperature a Hutchinson consistency equal to that of the mixture of tar and bituminous asphalt or asphalt for which it is to be substituted.

Another British patent (16) was issued to the South Metropolitan Gas Company in 1930. It described a process in which a dispersion containing 18 to 25 percent of coal in tar, with or without added pitch, was hot-mixed with hard stone in sufficient amount to produce a bituminous material of a prescribed consistency and "suitable for application by spreading while hot to a road foundation." Laboratory investigations of the kind that led to the development of the processes covered by the previously mentioned patents were described by E. N. Evans and H. Pickard in a 1931 publication (17) circulated by the South Metropolitan Gas Company.

Further use of coal digestion was made in Germany during World War II by Rühröl G.m.b.h. at Bottrop-Welheim. However, the process had no relation to the production of binders for road making purposes. Instead, bituminous coal was digested under relatively high temperatures and pressures with liquid-phase middle-oil produced by the hydrogenation of a $^{70}/_{30}$ mixture of briquet pitch and coal-tar oil. The digested mixture was filtered to remove undissolved coal and ash from the extract and the latter was distilled under vacuum. The distillate from this operation was returned to the hydrogenation plant for conversion into motor fuels and the distillation residue was carbonized in coke ovens to make ultra-pure coke for use in electrodes employed by the aluminum industry. The process known as the Pott-Broche process, has been described by Rhodes (18), Cockram (19), Lowry and Rose (20), and others.

A British patent (21) granted in 1958 to the Coal Tar Research Association, Gomersal, described a process for the preparation of a fluxed pitch "containing an organic thermo-plastic resin, natural or synthetic rubber or coal extract adapted to extend the plastic temperature range" in which the fluxing oil or fluxed mixture is "treated at an elevated temperature to remove fume-generating volatiles. The treatment may comprise straight distillation with or without the use of a fractionating column or stripping with an inert gas or oxidation by blowing with air." Reference is made in the patent to the use of the resultant product as "binder, adhesive, impregnant or coating including mastics, expansion jointing and road construction materials."

SELECTION OF PROCEDURES

The early investigations of the South Metropolitan Gas Company, England (15), indicated that the digestion of coal in a given coal tar alters its consistency but does not effect an appreciable alteration in its temperature-consistency relationship. The latter seemed to be accomplished by decreasing or increasing the pitch content of the tar in which the coal is digested by the addition or removal (by distillation) of tar oils. This was indicated also by early laboratory studies and field experiments made in the United States by the Koppers Company for the development of improved pipeline enamels and steep-roof pitches. For these purposes it was found necessary to disperse the coal in carefully adjusted mixtures of coal-tar pitch and high-boiling coal-tar oils. To confirm these earlier observations, as applied to pavement binders and to determine what the preferred procedure should be for making road binders by coal-digestion methods, it was decided by Curtiss-Wright to make both two- and three-component coal dispersions experimentally and to compare them with each other and with asphalt paving cements from various standpoints including temperature susceptibility. Throughout this discussion the term "two-component coal dispersions" refers to those containing only coal-tar and coal (CW-II). Three-component binders contain coal tar, coal, and high-boiling coal-tar oil (CW-III).

RAW MATERIALS

Of the various raw materials ordered for use in the early Curtiss-Wright investigations, those used to the greatest extent were the following:

1. 70-85 penetration asphalt meeting Pennsylvania State Highway Department specification A-1. Source: American Bitumuls and Asphalt Company, Baltimore, Md. Analysis: softening point (R and B), 51.8 C; sp. gravity at 25 C, 1.030; penetration 100 g - 5 sec., 71.0 at 25 C; 143.0 at 32 C; penetration 50 g - 5 sec., 50.1 at 25 C; 93.3 at 32 C. Asphalt meeting Pennsylvania 70-85 Class A-1 specifications was selected as a standard for comparison with the coal-digestion products because it is the softer, and was said to be the most frequently used penetration-grade asphalt binder specified by the Pennsylvania Highway Department for ID-2 (hot-mix, hot-lay) type, bituminous surface courses.
2. RT-12 grade coal tar meeting Pennsylvania Highway Department specification BM-2. Source: Koppers Company, Inc., Pittsburgh, Pa. Analysis: softening point (R and B), 33.0 C; sp. gravity at 25 C, 1.20; penetration 50 g - 5 sec., 176 at 25 C, 370 at 32 C; distillation to 170 C, 0.9 percent; to 270 C, 11.3 percent; to 300 C, 16.4 percent; softening point of distillation residue (R and B), 59.0 C; total bitumen (soluble in CS_2) 90.5 percent. RT-12 grade road tar is usually prepared in the United States by the straight distillation of high-temperature coal tar produced during the carbonization of bituminous coal in chemical-recovery, slot-type coke ovens. It was selected for use as the base material in the coal-digestion experiments because (a) large quantities of coke-oven tar are available in the United States; (b) a high degree of uniformity can be maintained due to the great similarity of coke-oven tars produced throughout the United States; (c) it is a topped tar from which have been removed most of the lower boiling constituents that, through evaporation and sublimation, are responsible for most of the hardening that takes place in tar roads, unless they are densely constructed or tightly sealed; (d) although RT-12 grade road tar is a soft pitch, it still contains the middle- and high-boiling oils that are known to be particularly effective as solvents or dispersing agents for bituminous coals. Also, the middle- and high-boiling oils are effective softeners or plasticizers for coal-digestion products.
3. High-boiling coal-tar oil meeting the special specifications of not more than 5 percent distillate to 315 C; 70 to 75 percent distillation residue at 355 C. Source: Koppers Company, Inc., Warren, Ohio. Analysis: moisture, 1.0 percent; sp. gravity at $^{38}/_{15.5}$ C, 1.155; total distillate to 270 C, 0 percent; to 300 C, 1.1 percent; to 315 C,

3.0 percent; residue at 315 C, 82.1 percent. The high-boiling coal-tar oil was to be used as a fluxing oil or plasticizer to supplement the oils of similar nature already contained in the RT-12. The particular boiling-range specifications previously given for the high-boiling oil were selected to insure the removal from such oil of comparatively volatile constituents that distill below 315 C and at the same time to insure the presence of a large proportion of coal-tar oils boiling between 315 and 355 C which are known to have good digesting or dispersing capacities for bituminous coals. The high-boiling oil from the Warren plant of Koppers Company, Inc., was particularly well stripped of low-boiling constituents by means of a fractionating column and for that reason was expected to be especially suitable for the intended purposes.

4. Lower Freeport seam coal from The Maple Hill Coal Company near Quehanna, Pa. Samples from The Maple Hill Coal Company, C seam, and from Orlando Brothers Coal Company, D seam, were compared with the Freeport seam coal. Each coal was pulverized to minus 200 mesh, mixed with RT-12 in the proportion of 4.8 percent coal to 95.2 percent RT-12. The mixture was heated, with agitation, for one hour at 600 F. Coal analyses and the softening points and penetrations of the digestion products made from the three coals are given in Table 1. The softening point of the RT-12 which originally was 33 C was raised only two degrees by digestion with seam C coal, whereas each of the other coals, although quite dissimilar with respect to volatile material, sulfur, and ash, raised the softening point seven degrees. Also their penetrations at 25 C were about alike and considerably lower than that of the digestion product from the seam C coal. Ensuing autoclave tests were made largely with the Lower Freeport seam coal.

LABORATORY AUTOCLAVE DIGESTIONS

By means of an electrically heated and mechanically agitated autoclave, especially designed and constructed for the purpose by Curtiss-Wright, numerous 1-gal batches of binder were made in which bituminous coal, pulverized to pass 100 percent through a 200 mesh sieve was mixed with RT-12, high-boiling oil or combinations of RT-12 and oil in varying proportions. With the agitator running, the mixture was poured into the autoclave through an opening in the top. Then, with side and top vents open to permit the escape of any moisture or low-boiling oils, the temperature was raised to 400 F by means of electric heaters surrounding both the still-pot and the still-cover. Heating was then continued, with agitation, to 600 F and that temperature was maintained for one hour. After cooling to 400 F the content of the autoclave were discharged through an internally seated bottom valve.

Experiments were performed in which (a) the top vent of the autoclave was left open throughout the entire heating and cooling period; (b) the top vent was connected to a reflux condenser to return to the autoclave any high-boiling oil that might be distilled from the charge during the heating period to and at 600 F; and (c) the top vent was tightly closed to prevent the escape of any gases or vapors from the charge. In the latter cases some pressure developed in the autoclave. It usually amounted to about 20 lb and in no case exceeded 50 lb.

Substantially no difference could be detected in the characteristics of digestion products made by the three different operating procedures. The use of distilled coal tar (RT-12) and high-boiling coal-tar oil minimized the amount of evaporation, distillation, or development of pressure that would have accompanied the use of lower boiling raw materials.

It was evident from the tests that neither pressure nor reflux is required to disperse bituminous coal effectively in RT-12, high-boiling coal-tar oil or mixtures of the two.

DIGESTION VS MECHANICAL MIXING OF COAL IN TAR OR TAR OILS

The consistency of a coal tar or high-boiling coal-tar oil can be increased somewhat by mechanically mixing finely pulverized coal with it. However, a much greater change in consistency can be effected with a given proportion of the same pulverized coal by digesting it in the tar or oil in the manner previously described, presumably because digestion causes the bituminous portion of the coal to be colloidally dispersed in the digesting medium. This was confirmed by experiments in the Curtiss-Wright laboratories in which 10.8 percent of pulverized bituminous coal was mechanically mixed with 89.2 percent of coal tar (RT-12) and with high-boiling coal-tar oil. Samples of the mixtures were removed for microscopic examination and consistency tests, and then 1-gal portions of each were digested in the autoclave at 600 F.

Photomicrographs were made of the original RT-12, the mechanical mixture of RT-12 with coal, and the dispersion made by digesting the mechanical mixture of RT-12 and coal at 600 F. The particles of pulverized coal were clearly visible in the picture of the undigested mechanical mixture but were not visible in the photomicrograph of the digestion product. Except for a few more large particles in the latter, it closely resembled the picture of the original RT-12. It was evident from the pictures that the dispersed particles of coal in the digested product were infinitely smaller than the tar-insoluble (C-1) particles in the original coal tar which are known to range in size from about 1 to 4 m.

Other photomicrographs showed that digestion of the same coal in the high-boiling tar oil reduced the minus 200 mesh coal particles, clearly visible in the undigested mixture, to such small dimensions that they were invisible under the microscope at 400 magnification. A few visible particles in the digested product appeared to be slate and other mineral matter from the coal which could not be colloidally dispersed by the digestion process. Changes in softening points and penetrations at 25 and 32 C resulting from the mixing and digesting experiments are given in Table 2. Mechanical mixing of 10.8 percent of coal with coal tar (RT-12) increased the softening point only 3.5 C, whereas an increase of 17.8 C resulted from digestion of a mixture containing the same proportions of coal and tar. The curves shown in Figure 1 were drawn by plotting the logarithms of the penetrations (50 g - 5 sec) at 25 and 32 C for the RT-12, the mechanical mixture of RT-12 with 10.8 percent coal and the dispersion of 10.8 percent coal in RT-12. The fact that the three curves are substantially parallel indicates that the temperature susceptibility of a given coal tar is not materially altered either by mixing or digesting the pulverized coal with the coal tar but the consistency (softening point) of the coal tar is increased to a greater extent by the digestion process as shown by the different spacings between the curves.

COAL CONCENTRATIONS VS SOFTENING POINTS AND TEMPERATURE SUSCEPTIBILITIES

A series of autoclave tests was performed using RT-12 and Lower Freeport seam coal to determine how softening points and consistency—temperature relationships are affected by varying the proportions of coal and tar. Also it was desired to know what the proportions should be to duplicate the softening point and/or temperature susceptibility of the 70/85 penetration asphalt selected for comparison.

TABLE 1

CHARACTERISTICS OF THREE BITUMINOUS COALS FROM QUEHANNA AREA AND OF 4.8 PERCENT DISPERSIONS OF EACH IN RT-12

Seam	Coals						Dispersions	
	Moisture (%)	V.M. (%)	F.C. (%)	S. (%)	Ash (%)	F.S. Index	S.P. R & B (°C)	Penetration (100g/5 sec/25 C)
Maple Hill C	0.43	22.41	58.65	4.45	18.94	7.0	35	218
Lower Freeport	0.48	23.25	61.71	5.18	15.04	8.0	40	145
Orlando D	0.80	26.44	67.74	1.00	5.82	8.5	40	141.9

TABLE 2

CHANGES IN SOFTENING POINTS AND PENETRATIONS OF RT-12 BY MECHANICALLY MIXING AND BY DIGESTING IT WITH COAL

Material	Softening Point (R & B)(°C)	Penetration 50 g/ 5 sec/ 25 C	Penetration 50 g/ 5 sec/ 32 C
RT-12	33.0	176	370
RT-12 plus 10.8% coal (mech. mix)	36.5	153.3	317
RT-12 plus 10.8% coal (digested)	50.8	28.6	61.5

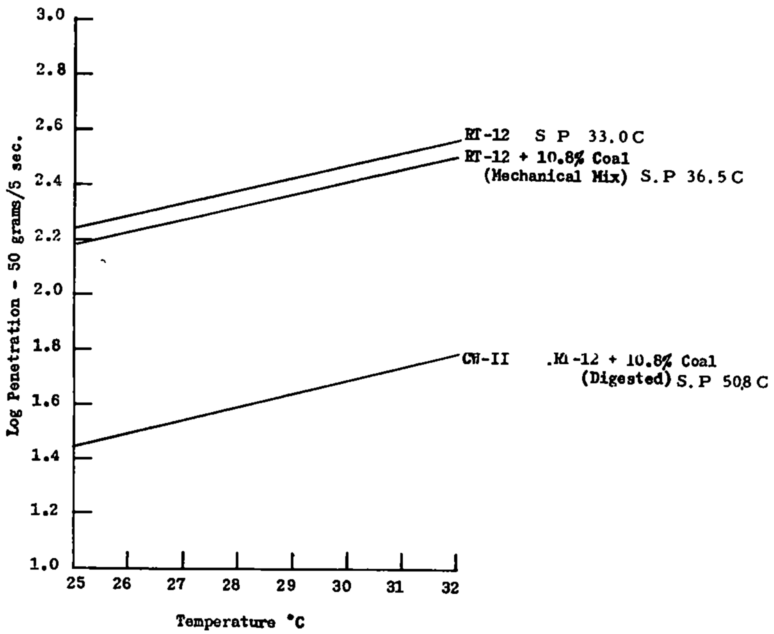


Figure 1. Comparison of mechanical mixture of coal and RT-12 with a digested mixture of same composition.

TABLE 3

COMPARATIVE SOFTENING POINTS AND PENETRATIONS OF RT-12, ASPHALT AND DISPERSIONS CONTAINING VARYING AMOUNTS OF COAL AND RT-12

Material	Softening Point (R & B)(°C)	Penetration 50 g/ 5 sec/ 25 C	Penetration 50 g/ 5 sec/ 32 C
RT-12	33.0	176	370
CW-II:			
5% coal + 95% RT-12	40.0	94	215
8% coal + 92% RT-12	46.0	42.3	101
10.8% coal + 89.2% RT-12	50.8	28.6	61.5
12.0% coal + 88.0% RT-12	54.3	16.5	41.7
Pa A-1, (70/85 pen asphalt)	51.8	50.1	93.3

The effect of varying coal concentrations on softening points and also on penetrations at 25 and 32 C (50 g - 5 sec) are given in Table 3. The softening point of the coal dispersion containing 10.8 percent coal (50.8 C) most nearly duplicated that of the 70-85 penetration asphalt (51.8 C).

Figures 2 and 3 were prepared from the data in Table 3. The curves in Figure 2 indicate the rates at which the softening points increased and penetrations decreased with increasing coal concentrations. Although the softening points of the coal dispersions increased with increasing coal concentrations the parallel log penetration-temperature curves in Figure 3 indicate that they all had substantially the same temperature susceptibilities as the original RT-12 to which no coal had been added. Also their steeper curves indicated that they were all poorer in this respect than the 70-85 penetration asphalt cement.

It was concluded from this series of experiments that to approximate the penetration at 25 C of a given asphalt cement a dispersion of coal in tar should have a somewhat lower softening point, but even with that adjustment, the coal dispersion could be expected to have a poorer temperature susceptibility than the asphalt. In Figure 3, this is shown by the difference in the slopes of the curves for the 70-85 penetration asphalt (S. P. 51.8 C) and the dispersion containing 8 percent coal (S. P. 46 C).

TEMPERATURE SUSCEPTIBILITIES OF COAL-TAR PITCHES

Before proceeding further with attempts to improve the temperature susceptibilities of coal-digestion road binders, it was decided to distill a sample of RT-12 in the autoclave to various grades of pitch and determine the temperature susceptibility of each.

Figure 4 shows log penetration-temperature curves for a sample of RT-12 having a softening point of 33 C and for two pitches derived therefrom by distillation (5 and

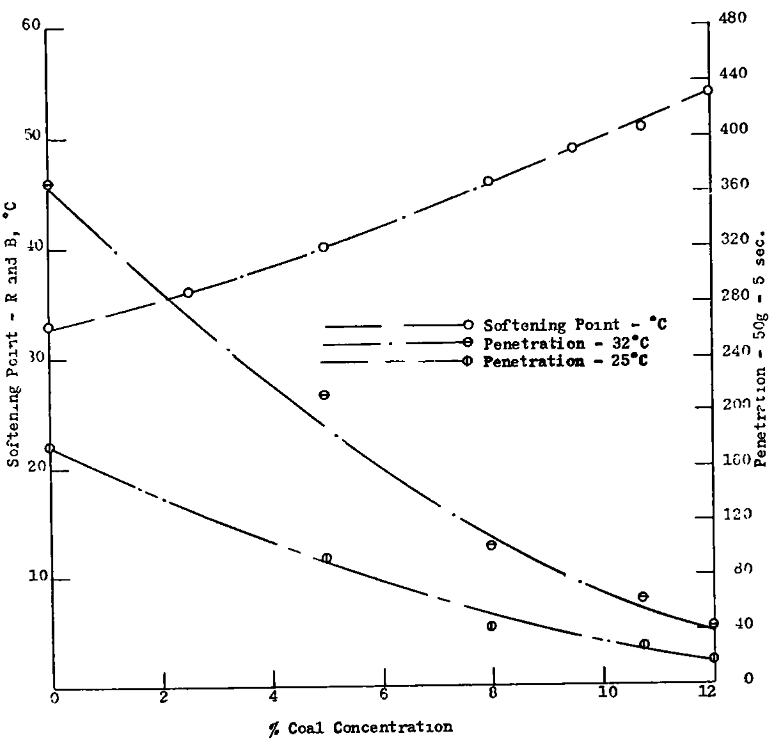


Figure 2. Coal concentration vs softening point and penetration for CW-II binders (coal dispersions) containing RT-12 and Pennsylvania Lower Freeport seam coal, sample 103-98-1.

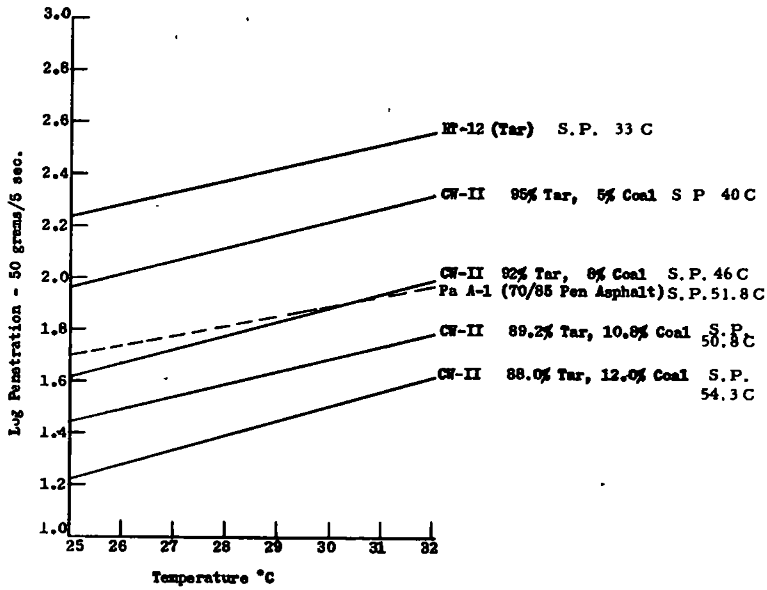


Figure 3. Temperature susceptibilities of coal dispersions containing varying amounts of coal compared with those of RT-12 and asphalt cement.

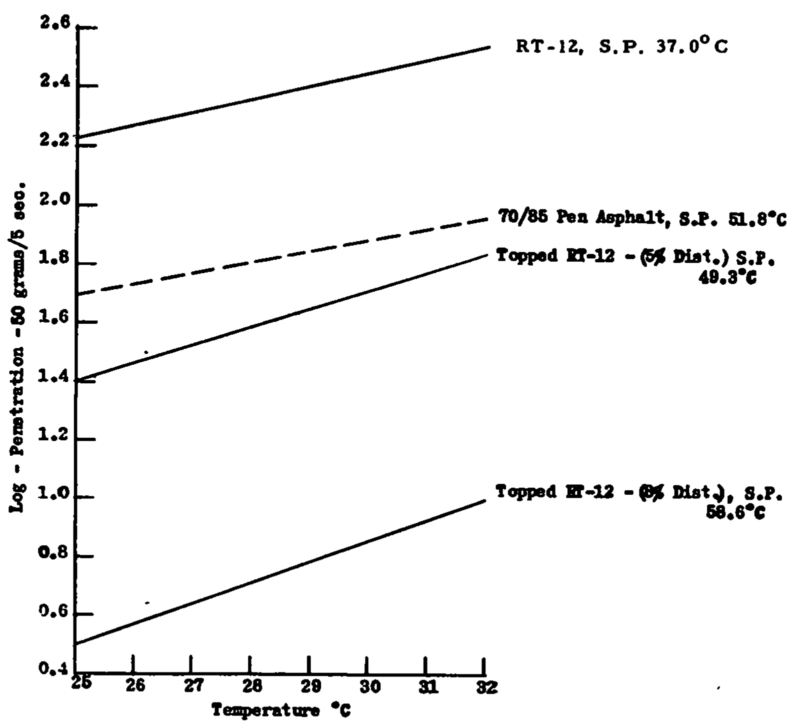


Figure 4. Comparison of log penetration-temperature relationships for RT-12, topped RT-12 (pitches), and 70-85 penetration asphalt (Pa A-1).

8 percent distillate, respectively). The curves show that removal of increasing amounts of oil from coal tar causes the resulting pitches to have progressively higher (poorer) temperature susceptibilities than the original coal tar. The high-boiling constituents of tar which remain as pitch when the tar is distilled appear to have the highest (poorest) temperature susceptibilities. When their concentration in the tar is increased by removal of some of the lower boiling constituents the temperature susceptibility of the tar is increased; i.e., it is made poorer as compared with asphalt. Conversely, if coal-tar oil is added to the tar, thereby decreasing its content of pitch or pitch forming constituents, the temperature susceptibility of the tar is lowered (improved).

IMPROVEMENT OF COAL DISPERSIONS WITH COAL-TAR OILS

The ability of high-boiling coal-tar oils to improve (lower) the temperature susceptibilities of coal tars was found to apply to the improvement of coal-digestion, steep-roof pitches and pipeline enamels first developed in the United States by the Koppers Company.

Compared with other materials considered by the Curtiss-Wright investigators for improving the temperature susceptibilities of coal-digestion types of hot-mix road binders, high-boiling coal-tar oils were believed to have the following advantages: (a) they are completely miscible in all proportions with coal tars and pitches derived therefrom, (b) they are compatible with dispersions of coal in tar, and (c) when used as diluents or fluxing agents for the latter, they tend to decrease rather than increase their volatilities at atmospheric temperatures.

To determine the optimum proportions of high-boiling oil to be used in coal-digestion binders made from Pennsylvania coals, several autoclave digestions were made with varying proportions of coal, RT-12, and high-boiling oil. The softening points and penetrations of four dispersions of this type and of the 70-85 penetration asphalt cement are given in Table 4, and from these data the temperature-susceptibility curves (log penetration-temperature) shown in Figure 5 were prepared. They appear to indicate the following:

1. The temperature susceptibilities of the four coal-modified binders were improved consistently with increasing high-boiling oil contents although different proportions of coal and tar, in addition to oil, were used in each case.
2. Two of the binders containing 28.5 percent and 24.2 percent of oil, respectively, had approximately the same slopes (temperature susceptibilities) as the asphalt, also their softening points were about the same (45.5 and 45.8 C) and both softening points were about six degrees lower than that of the asphalt (51.8 C). The softening points of these two C-W III binders were almost identical to that of the C-W II binder (46 C), which most nearly duplicated the temperature susceptibility of the 70-85 penetration asphalt as shown in Figure 3 but the slopes of the two C-W III binders (Fig. 5) coincided more exactly with the asphalt curve than did the slope of the 46 S.P. C-W II binder.

TABLE 4

SOFTENING POINTS AND PENETRATIONS OF ASPHALT AND OF DISPERSIONS CONTAINING VARIOUS PROPORTIONS OF RT-12, COAL AND HIGH-BOILING COAL-TAR OIL

Material	Tar (%)	Coal (%)	Oil (%)	S.P. (R&B)(°C)	Penetration 50 g/5 sec/25 C	Penetration 50 g/5 sec/32 C
CW-III	83.3	8.3	8.3	40.8	87.0	219.0
	20.0	20.0	60.0	47.0	76.2	127.3
	52.5	19.0	28.5	45.8	50.8	108.0
	64.4	11.4	24.2	45.5	43.8	91.5
Pa A-1 (70/85 pen asp)				51.8	50.1	93.3

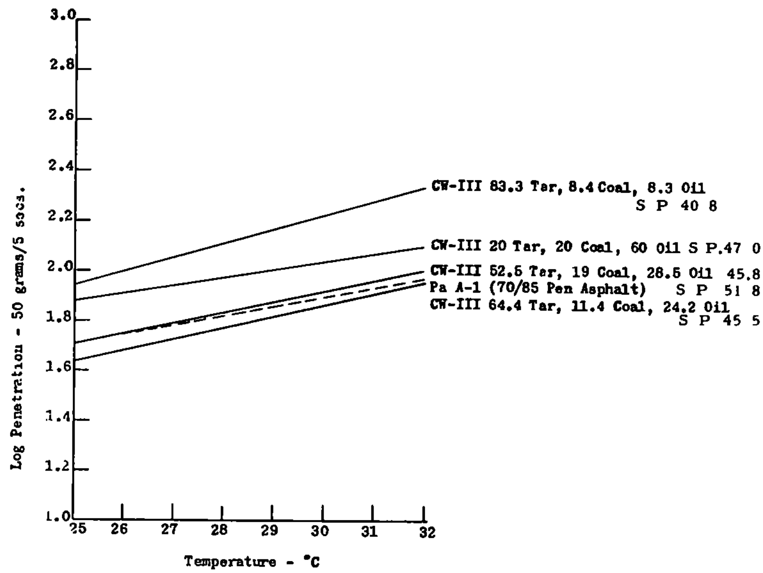


Figure 5. Temperature susceptibilities of asphalt and coal dispersions containing various amounts of coal, RT-12, and high-boiling coal-tar oil.

3. The slope of the curve for the C-W III binder containing 60 percent of high-boiling oil is not as steep as that of the asphalt, which appears to show that coal-digestion binders can be produced that will have temperature susceptibilities even better than those of paving asphalts.

COMPARISON OF COAL-DIGESTION BINDERS WITH ASPHALT AND RT-12

From the numerous two-component (C-W II) and three-component (C-W III) coal dispersions prepared in the course of the investigations previously discussed, one of each type was selected for more detailed comparison with the 70-85 asphalt and with RT-12. Comparative laboratory test data for the four binders are given in Table 5. With two exceptions, all the data were obtained with standard ASTM procedures—the aqueous stripping or adhesion test and the jet fuel (JP-4) solubility test. They were performed as follows:

Aqueous Stripping Test

Into 1 l of distilled water, heated in a beaker to 60 C and stirred vigorously by means of a mechanical agitator, was introduced a 50-g portion of a previously prepared mixture containing 98 percent by weight of standard 20-30 mesh Ottawa sand and 2 percent of the binder to be tested. After 15 min, during which agitation was continued and the temperature of the water was maintained at 60 C, the contents of the beaker were poured through a standard 20 mesh sieve mounted loosely above a sieve pan to allow the bulk of the water to drain away from uncoated particles that passed through the sieve and remained in the pan. Coated sand grains retained on the 20 mesh sieve were washed vigorously with a stream of water at 60 C to wash any remaining uncoated particles through the sieve and into the pan. Water was then decanted as completely as possible from the uncoated sand grains in the pan and, after drying the pan and contents on a hot plate, the weight of uncoated sand was determined. This weight divided by that of the original sample (50 g) was reported as the percentage by weight of sand grains from which the binder had been stripped by agitation in water at 60 C for 15 min.

TABLE 5

COMPARATIVE TEST RESULTS FOR 70-85 PEN. ASPHALT, RT-12 AND COAL-MODIFIED RT-12 BINDERS WITH AND WITHOUT HIGH-BOILING COAL-TAR OIL

Property	Sample			
	Pa. A-1	CW-III	CW-II	RT-12
Sample No.	13-111-1	96-79-1	96-67-1	103-73-1
Composition (wt. %):				
70-85 pen. asphalt	100	--	--	--
Freeport seam coal	--	11.4	10.8	--
Distilled C.O. tar (RT-12)	--	64.4	89.2	100
High-boiling coal-tar oil	--	24.2	--	--
Sp. gravity at 25 C (D 70-52)	1.030	1.242	1.255	1.200
Softening pt. R & B (D 36-26)	51.8	45.5	50.8	33.0
Bitumen (% CS_2 sol) (D 4-52)	--	76.7	74.4	90.5
Flash pt., open cup (D 92-52)	--	368 F	--	--
Distillation (%) (D 20-55):				
To 170 C	--	0	0	0.9
To 270 C	--	0.18	7.5	11.3
To 300 C	--	5.21	12.6	16.4
Soft. pt. of distn. res. (D 36-26)	--	80.0	83.8	59.0
Penetration (D 5-52):				
100 g/ 5 sec/25 C	71.0	65.3	38.0	--
50 g/ 5 sec/25 C	50.1	43.8	28.6	176
100 g/ 5 sec/32 C	143.0	129.3	79.0	--
50 g/ 5 sec/ 32C	93.3	91.5	61.5	370
Loss on heating (%) 5 hr, 325 F (D 6-39 T)	0.08	2.12	2.53	10.1
Pen. of res. after 5 hr 325 F (D 5-52):				
100 g/ 5 sec/ 25 C	66.4	21.4	15.0	11.0
50 g/ 5 sec/ 25 C	44.7	12.1	8.3	--
100 g/ 5 sec/ 32 C	119.7	45.5	30.5	52.5
50 g/ 5 sec/ 32 C	81.1	30.8	18.6	34.0
Soft. pt. of res. after 5 hr 325 F (D 36-26)	50.3	55.8	59.8	50.3
Sp. gr. of res. after 5 hr 325 F (D 70-52)	1.030	1.245	1.255	1.20
Aqueous stripping (%) (sand mix)	47	0	14.0	0
Solubility in jet fuel (%) (sand mix)	97.1	16	16	11.6

JP-4 (Jet Fuel) Solubility Test

A 100-g portion of a previously prepared mixture containing 98 percent of standard 20-30 mesh Ottawa sand and 2 percent of the binder was introduced into a 300-ml Erlenmeyer flask containing 100 ml of JP-4. The flask was stoppered, placed in a mechanical shaker, and agitated vigorously for 15 min. The flask was then removed from the shaker, the solution of dissolved bitumen in JP-4 was decanted into a graduate, and the sand remaining in the shaker was washed with two 50-ml portions of JP-4. The washings were added to the first extract and the combined extracts were made up to 200 ml with additional JP-4. By means of a pipette, a 40-ml portion of the decanted solution was then transferred to a tared evaporating dish, evaporated on a steam bath, and then dried to constant weight in an oven at 150 C. The weight of the bitumen remaining in the evaporating dish was determined, and this weight, multiplied by 5, was taken as the total weight of extracted bitumen. The latter divided by 2 g (the weight of bitumen in the original 100-g sample of mixture), was reported as the percentage of binder dissolved by JP-4.

TESTS ON ASPHALT, COAL TAR, AND COAL-MODIFIED TAR BINDERS

From the data given in Table 5 it appeared that of the three coal-tar materials (CW III, CW II, and RT-12) the one containing high-boiling coal-tar oil in addition to coal and RT-12 (CW III) should compare most favorably with asphalt as a hot-mix binder. This table and Figure 6 show its penetrations at 25 and 32 C most nearly coincided with those of the 70-85 asphalt cement although its softening point was approximately six degrees lower.

When distilled to 300 C, the distillate yield of the CW III was much lower than those from the CW II and RT-12. Also, its loss on heating for 5 hr at 325 F was somewhat less than that of the CW II and much lower than the loss from the RT-12. These tests indicated that the oil and coal-modified RT-12 (CW III) should be less volatile at elevated temperatures than either the CW II or RT-12 but it would be somewhat inferior to the 70-85 asphalt in this respect.

The aqueous stripping and jet-fuel solubility tests showed that the CW III should be far superior to the 70-85 asphalt and at least equal to the CW II and RT-12 binders with respect to adhesion to aggregates and insolubility in petroleum fuels.

COMPARISON OF HOT-MIXES CONTAINING DIFFERENT BINDERS

Having compared coal-digestion types of binders (CW III and CW II) with RT-12 and with a typical asphalt cement, additional tests were performed to compare hot mixes containing each of them in combination with a typical limestone aggregate.

Crushed limestone of two sizes (½ in. to dust and ¼ in. to dust) meeting Pennsylvania Department of Highways specifications for Type A stone, Sections 2.3.2 and 2.3.5, was obtained from the Rockview Quarry of the E. W. Markle Company, Pleasant Gap, Pa.

The stone was thoroughly dried in a constant-temperature oven and then screened into fractions which were recombined in the proportions given in Table 6 each time that a batch of hot mix was needed for test purposes.

Recombination of the fractions in these proportions produced a mixed aggregate having the gradations given in Table 7.

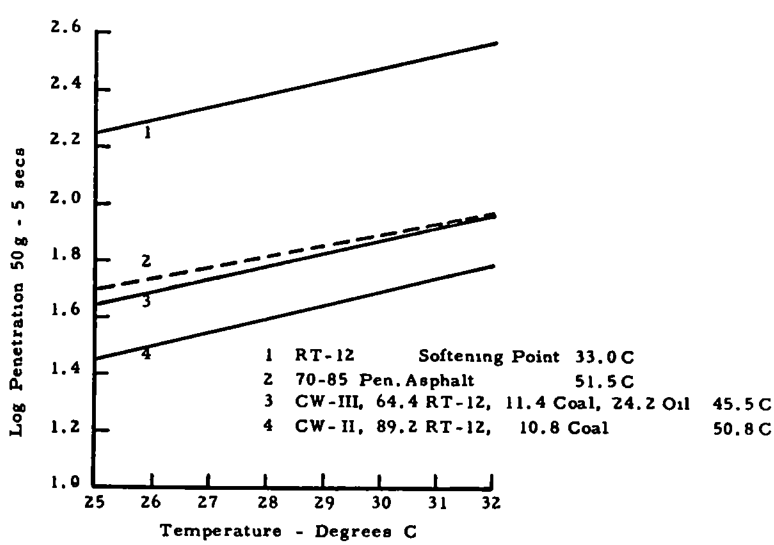


Figure 6. Temperature susceptibility curves for RT-12, asphalt, and coal dispersions in RT-12 with and without high-boiling coal-tar oil.

TABLE 6

Stone Fraction (%)	Sieve Size
32	3/8 in. - No. 4
30	No. 4 - No. 10
15	No. 10 - No. 40
13	No. 40 - No. 100
3	No. 100 - No. 200
7	Passing No. 200

TABLE 7

Aggregate (% passing)	Sieve Size
100	3/8-in.
68	No. 4
52	No. 8
38	No. 16
28	No. 30
19	No. 50
10	No. 100
7	No. 200

This gradation, which is close to the upper limits of the Pennsylvania specification range, was selected for the Curtiss-Wright experiments because, in addition to complying with the Pennsylvania hot-mix specifications, it also approximated the average gradation of aggregate mixtures recommended by American tar distillers for use in the production of hot-mix, hot-lay tar concretes in which road tars of the RT-11 or RT-12 grades are used as binders.

Each batch of hot mix produced for test purposes weighed 27 lb. The following procedure was used. Calculated amounts of the various stone fractions, except the Nos. 100 to 200 and fines passing No. 200, were weighed into the bowl of a mechanical mixer and heated in the oven 275 to 300 F for CW II, CW III, and asphalt mixes and 200 to 225 F for RT-12 mixes. The binder, in a separate container, was melted and heated to the desired temperature on a hot plate. For RT-12 the temperature was approximately 175 F and for CW and asphalt binders 275 to 300 F.

The bowl containing the heated aggregate mixture (minus the fractions passing No. 100), was placed in a mechanical mixer and the dry aggregate was stirred vigorously for 30 sec. A weighed amount of the preheated binder was added, and stirring was continued for 15 sec after which the fractions smaller than 100 mesh were added and agitation was continued for an additional 30 sec or until all stone particles appeared to be thoroughly coated.

Weighed portions of the hot-mix were then molded into test specimens (briquets) of 4-in. diameter and 2 ½-in. thickness using molds and 10-lb compacting hammers of the Marshall type. Each specimen was compacted with 50 blows of the hammer on each face.

To determine the optimum binder content for each type of binder, four separate batches of hot mix were made containing different proportions of binder and nine specimens were made from each batch. The molded specimens were then tested for stability and flow after immersion in water at 140 F for 25 min; unit weight per cubic foot; percent voids (total mix); and percent aggregate voids filled, in accordance with the procedures specified for the Marshall method of mix design outlined by the Asphalt Institute in its manual, Series 2, 1st edition, April 1956, pp. 19 - 38.

Using optimum binder contents calculated from data resulting from the previously mentioned tests, additional specimens were made and tested for impact resistance, loss on heating, jet fuel solubility, and change in stability after immersion in warm water (120 F). These four special tests were performed as follows:

Impact Test

A guided 5-kg weight was dropped onto a 1-in. steel ball held loosely by means of a steel plate in the center of the upper surface of a specimen previously cooled to either of two test temperatures (approximately 77 and 32 F). The 5-kg weight was first dropped onto the steel ball from a point 1 in. above it (2 in. above the specimen). The height of drop was then increased 1 in. at a time until a crack appeared in the specimen. The height of drop at that time (or number of drops since they were the same) was recorded as the impact resistance of the specimen.

Loss on Heating

Carefully weighed specimens (Marshall briquets) were placed in a constant temperature oven maintained at 140 F and after 72 hr were cooled and reweighed. From the weighings made before and after the heating period the average loss in weight was calculated. Some of the specimens were immersed in water at 140 F for 25 min and tested immediately for Marshall stability. Others were cooled to room temperature and to 32 F and tested for impact resistance by the method described previously.

Jet Fuel Solubility

Specimens from hot-mixes containing optimum amounts of the four different binders were immersed in jet fuel (JP-4) at room temperature. After 48 hr the specimens were removed, placed on paper towels (to absorb jet fuel), and allowed to stand exposed to the atmosphere for 2 days. The loss in weight for each specimen was then calculated from weighings made before and after immersion in the jet fuel.

Water Immersion

For the water immersion tests, specimens were made from a more open aggregate mixture. All fines smaller than 40 mesh were omitted from the regular mix used for the other tests previously described. The open mix was made by combining 41.6 percent of the ⅜-in. to No. 4 fraction with 26 percent of No. 4 to No. 10 and 32.4 percent of No. 10 to No. 40. Binder contents were 4 percent by weight for the RT-12 and CW binders and 3.6 percent by weight for the asphalt binder. Because of differences in the specific gravities of the different binders, volume percentages were approximately equal. Some of the specimens made with each type of binder were tested for Marshall stability in the standard manner and others were tested for stability after immersion in water at 120 F for 96 hr. The average change in stability for each type of binder was then calculated.

SUMMARY OF TEST RESULTS

The results of the tests performed on hot mixes made with RT-12, 70-85 asphalt cement, CW II and CW III are summarized in Table 8. The percent binder, by weight, at optimum binder content for each of the two CW binders was somewhat higher than that of the asphalt binder. However, because of their different specific gravities their respective volume percentages were approximately the same.

Marshall stabilities with both of the CW mixes were about 50 percent higher than that of the asphalt mix and about 100 percent higher than the stability of the RT-12 mix. Flow numbers for the CW mixes were intermediate between those of the asphalt and RT-12 mixes. The CW mixes and asphalt mix were very similar with respect to unit weight, percent voids filled and percent voids total mix. Impact tests were slightly better for the asphalt mix.

The heating of asphalt and CW III briquets at 140 F for 72 hr caused the latter to lose 0.6 percent as compared with a loss of 0.04 percent from the asphalt briquets. The 72-hr heating test caused the asphalt briquets to suffer a greater decrease in Marshall stability (20 percent) than the CW III briquets (3 percent). It also caused a decrease in the impact resistance of the asphalt briquets at 32 F, whereas that of the CW III briquets increased appreciably.

Jet fuel solubility of asphalt briquets was approximately 20 times greater than that of the CW III briquets. Immersion in water for 96 hr at 120 F caused a 17 percent decrease in the Marshall stability of asphalt briquets, whereas briquets made with CW III, CW II, and RT-12 binders increased in stability by 88, 9, and 14 percent, respectively.

MODELS FOR DEMONSTRATING DIFFERENCES IN BINDERS

In addition to performing the tests from which the experimental results given in Tables 5 and 8 were obtained, models were built in the Curtiss-Wright laboratories

T.\BLE 8

COMPARATIVE TEST RESULTS ON AGGREGATE HOT-MIXES CONTAINING ASPHALT, RT-12 AND COAL-MODIFIED RT-12 BINDERS WITH AND WITHOUT HIGH-BOILING OIL

Property	Sample			
	70/85 asphalt	CW-III[a]	CW-II[b]	RT-12
Sample No.	Pa A-1	96-79-1	96-67-1	
Softening point R & B	51.8	48.5	50.8	33.0
Percent binder at optimum	5.0	5.9	6.0	5.0
Marshall stability at optimum	2,290	3,344	3,350	1,744
Marshall flow at optimum	17.4	11.0	10.4	7.7
Unit weight (lb/cu ft) at optimum	14.9	15.2	15.1	--
% voids filled—agg. at optimum	83.0	85.0	80.0	--
% voids total mix at optimum	3.2	2.2	3.2	--
Impact tests at optimum:				
At 77 F	28	23.0	23.0	--
32 F	23	19.0	25.0	--
Jet fuel solubility	38.1	2.1	--	--
Change in marshall stability after 96 hr in water at 120 F (%)	-17	+88	+ 9	+14
Loss on heating (% by wt) (72 hr at 140 F)	0.04	0.6	--	--
Marshall stability after loss on heating test	1,836	3,234	--	--
Impact tests after loss on heating test:				
At 77 F	46	33	--	--
32 F	17	28	--	--

[a]CW-II: 89.2 percent RT-12, 10.8 percent coal.
[b]CW-III: 64.4 percent RT-12, 11.4 percent coal, 24.2 percent high-boiling oil.

to demonstrate the superior jet-fuel resistance, skid resistance, and resistance to pavement shoving or rutting obtainable with hot-mix binders of the coal-digestion types.

In the case of the jet fuel solubility demonstration, the fuel was allowed to drip at a uniform rate onto hot-mix panels made with the same aggregate but different binders. Jet fuel leaving the CW III panel was only slightly colored, whereas that leaving the asphalt panel was dark brown in color.

The skid resistance test was demonstrated by an electrically propelled toy automobile which had sufficient traction on the wet surface of a CW III hot-mix panel to lift a weight suspended from a cable attached to the car, whereas it had too little traction on the wet surface of an asphalt panel to lift the same weight.

In the rutting demonstration, a weighted miniature rubber tire pressed downward on the surface of a rotating table that had embedded in its surface three hot-mix panels containing asphalt, CW III binder, and RT-12. The three surfaces were heated equally to about 140 F by a heat lamp under which they passed as the table rotated. The deepest rut was formed on the panel containing RT-12 and the least rutting occurred on the CW III panel.

PUBLIC ANNOUNCEMENT OF QUEHANNA INVESTIGATIONS

Public announcement of the Quehanna investigations was made on April 7, 1959 in Harrisburg, Pa., of the results of laboratory tests, and the demonstration models were exhibited in support of the tentative conclusions based on the laboratory investigations that it should be possible to produce improved, coal-based binders for use in the construction of bituminous pavements of the hot-mix, hot-lay type.

A principal purpose of the meeting was to interest highway departments in the possibility of constructing experimental pavements in which coal-based binders would be subjected to actual service conditions and for which sufficient quantities of binder would need to be produced to establish the feasibility of making such binders satisfactorily on a commercial basis.

Shortly thereafter negotiations were started between Curtiss-Wright officials and State and highway department officials from Kentucky for construction and operation of a pilot plant for the production and delivery of 150,000 gal of coal-based binder to the Kentucky Department of Highways, and the latter would arrange for the use of such material for the construction of highway test sections in various parts of the State.

DESIGN, CONSTRUCTION, AND OPERATION OF KENTUCKY PILOT PLANT

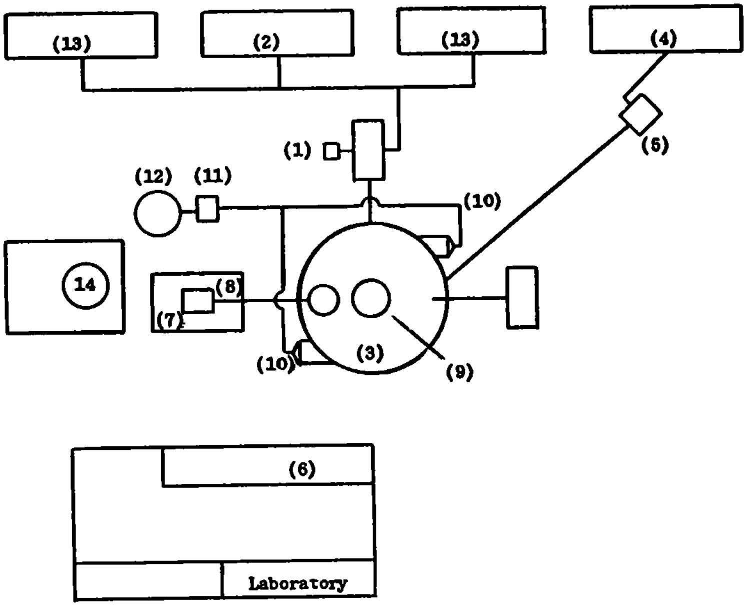
Design of the pilot plant for Kentucky was started in June 1959. Design specifications were completed on July 14, 1959. Construction finished on August 13, 1959.

The pilot plant was located at the Central Garage of the Kentucky Department of Highways in Frankfort. Operation of the plant, whose arrangement is shown in Figure 7 was as follows: RT-12 was transferred by means of an Etnyre pump (1) from tank car storage (2) to a 1,500-gal digester (3). High-boiling coal-tar oil was then transferred to the digester from tank storage (4) by means of a Viking oil pump (5). Pulverized coal in paper bags was transferred by truck from building (6) to platform (7) from which it was loaded into the digester with a screw conveyer (8). The coal tar, high-boiling oil, and coal were intimately mixed during loading of the digester and throughout the entire heating, digesting, and cooling periods by a high-speed impeller driven by a motor (9) mounted on the top of the digester. Heating of the batch was effected by means of two North American Burners (10) supplied with fuel oil by pump (11) from tank (12). A coal-fired 100-lb boiler (14) furnished steam for the heating of transfer lines and tank cars. It was inadequate in cold weather and was supplemented by a bituminous booster and portable high-pressure boiler. Compressed air was used for blowing transfer lines.

The temperature of the batch in the digester was raised as quickly as possible to 600 F and then held at that point for 30 min after which a water-cooling coil inside the digester lowered the temperature quickly to about 400 F. After testing for softening point, the batch of finished binder was transferred by the Etnyre pump (1) from the digester to tank car storage (13) or to tractor trailers for immediate transport to a job site.

During the period between August 13 and November 7, 104 batches of hot-mix binder totaling 152,070 gal at 60 F were delivered to 14 test sites from the pilot plant. One hundred batches were of the three-component type (CW III) with the average composition of 81 percent RT-12, 11.0 percent h-b oil, 8 percent coal. Two batches were of the two-component type (CW II) with an average composition of 96 percent RT-12 and 4 percent coal. The other two batches consisted entirely of RT-12. They were merely heated in the digester before transporting them to two different job sites.

The RT-12 used in the Kentucky pilot plant came from the Hamilton, Ohio plant of Koppers Company, Inc., and from the Ironton, Ohio, plant of Allied Chemical and Dye Corporation. The high-boiling coal-tar oil was received from the Follansbee, W. Va. plant of Koppers Company, Inc. Coal was purchased from the Eastern Coal Corporation and from the Hart and Hart Coal Company. Specifications under which RT-12 and high-boiling coal-tar oil were purchased for Kentucky were the same as those used for the procurement of samples employed in the laboratory investigations at Quehanna.



LEGEND

1. Etnyre Tar Pump
2. RT-12 Storage
3. Digester
4. H. B. Oil Storage
5. Viking Oil Pump
6. Coal Storage
7. Coal Loading Platform
8. Coal Conveyor
9. Agitator Motor
10. Oil Burners
11. Fuel Oil Pump
12. Fuel Oil Tank
13. C-W Binder Storage
14. Boiler

Figure 7. Curtiss-Wright pilot plant layout, Frankfort, Ky.

RAW MATERIALS AND BINDER FORMULATIONS

Kentucky pilot plant operations were based on information provided by investigations conducted at the Quehanna laboratories. As the result of the extensive studies conducted there during several months before the signing of the Kentucky agreement, it was decided that the preferred binder for use in the Kentucky experiments should be of a three-component type; i.e., it should contain coal tar (RT-12), high-boiling coal-tar oil, and coal. However, to establish definite operating procedures and formulations for Kentucky it was necessary to examine and test the raw materials and particularly the coals that would actually be used. This was done while the pilot plant was being designed and constructed.

Fifty-four different coal samples received from various mines in Kentucky were analyzed and tested on a miniature scale for digestibility in RT-12 after which three selected samples representing average eastern and western Kentucky coals were made into hot-mix binders in the 1-gal autoclave. They, in turn, were mixed in varying proportions with Kentucky aggregates to establish the optimum binder content for Class I hot mixes in which they were to be used. By agreement with the Highway Department this was originally set at 7.0 percent by weight for Curtiss-Wright binders, and later changed to 6.9 percent by weight.

LOCATING AND CONSTRUCTING OF TEST SECTIONS

While the pilot plant was being designed and constructed and the Quehanna investigations were in progress, members of the Research Division of the Kentucky Department of Highways, which had been designated to administer the contract, were inspecting possible test sites in various parts of the State. Visual surveys were made at 50 locations from which 20 were selected for further consideration.

Finally twelve locations were chosen at which 13 test sections totaling approximately 11 miles in length were installed. In addition, a short trial section, only 750 ft long, was constructed first near the pilot plant on a road (RT-1211) which originally had not been included in the testing program. The routes, locations, types, and lengths of the 14 test sections are given in Table 9.

Twelve of the test sections were of the 1 ½-in. overlay type. They were mixed and laid in accordance with Kentucky Highway Department specifications for bituminous concrete surface (Class I), surface course type B. In each case except the first (Frankfort, RT-1211), the hot mix was laid over an existing black top (asphalt) pavement that was in need of resurfacing because of poor skid resistance, excessive wear, or deterioration caused by base failures. In the other two locations the hot mix was laid directly over a tar-primed soil road in accordance with a special Kentucky specification designated as 2 ¾-in. Class I modified base. In every location arrangements were made for the construction of a standard Kentucky pavement surface with PAC (asphalt) binder close to or adjoining the Curtiss-Wright test section so that a direct comparison could be made of the Curtiss-Wright and asphalt binders under identical conditions.

No major difficulties accompanied the manufacture or laying of hot mixes made with the Curtiss-Wright binders. Whereas some contractors anticipated difficulties

TABLE 9

LOCATIONS, TYPES AND LENGTHS OF COAL-MODIFIED TAR BINDER TEST SECTIONS IN KENTUCKY

Route	Location	Type	Length (ft)
Ky 1211	Frankfort	1 ½ in. Class I	750
US 60	12 mi NE of Morehead	1 ½ in. Class I	4,963
US 460	6 mi East of Frankfort	1 ½ in. Class I	3,345
Ky 114	0.5 mi Southeast of Salyersville	1 ½ in. Class I	4,163
Ky 618	Southeast of Bredhead—1 mi East of intersection of Ky 70 and Ky 618	2 ¾ in. Class I modified base	2,403
Ky 39	6 mi south of Lancaster at Garrard-Lincoln County line	1 ½ in. Class I	4,443
US 421	7 mi North of Jackson-Clay County line near Tyner	1 ½ in. Class I	5,384
Ky 185	12 mi North of Bowling Green	2 ¾ in. Class I modified base	2,213
Ky 699	4.5 mi South of Intersection of Ky 699 and Ky 7 South of Hazard, Ky.	1 ½ in. Class I	5,855
Ky 101	From Scottsville running North	1 ½ in. Class I	3,557
Ky 70	South from intersection of Ky 70 and Ky 85 East of Madison	1 ½ in. Class I	5,240
US 150 and US 31E	8 mi North of Bardstown	1 ½ in. Class I	5,260
US 25	Main Street, London	1 ½ in. Class I	5,280
US 25	8 mi South of London	1 ½ in. Class I	5,280

in transferring and metering the special Curtiss-Wright binders, none were encountered. The good laying characteristics of the Curtiss-Wright mixes were particularly noticeable. Both contractors and paver operators commented on their quick "set-up" that permitted rolling close to the pavers and made it possible for traffic to pass over newly laid surfaces somewhat sooner than usual without damage to the pavement surfaces or edges.

Following are references to some minor difficulties that were encountered in various locations. They are based on reports submitted by Curtiss-Wright's field engineer who was present during the construction of each test section.

1. At several plants the use of fuel oil or diesel oil to remove asphalt binder from transfer lines and metering equipment prior to the use of Curtiss-Wright binder caused the first batch of Curtiss-Wright hot mix to be contaminated. Picking-up, scabbing, or cracking occurred on some of the contaminated pavement surfaces.

2. Somewhat excessive fuming at the paver was noticed when the temperature of the hot mix at that point exceeded 260 F. Little fuming took place below that temperature and no laying difficulties were encountered when mix temperatures at the paver were as low as 200 F.

3. In several locations the asphalt emulsion tack coats were applied unevenly, were poorly distributed over the existing pavement surfaces, were partially or entirely removed by rain or were frozen by cold weather before the application of the hot mixes.

4. Unevenness in some of the pavements resulted from excessive cooling of the hot mixes before laying due to inadequate manpower or waiting for the arrival of trucks from distant hot mix plants.

5. On the modified base jobs, there was considerable segregation of coarse aggregates and some cracking and unevenness due to weak spots and rock shelves in the soil bases.

Probably the most serious damage to any of the newly laid Curtiss-Wright pavements occurred on US 25 in and near London, Ky. For the most part they were laid when atmospheric temperatures were extremely low (27 to 38 F). During the prolonged and unusually severe cold spell immediately following their installation, they were abraded and scarred excessively by tire chains probably because too little densification was obtained either during initial rolling or subsequently under traffic. Somewhat open surfaces resulted that were more severely damaged by alternate freezing and thawing conditions and by the abrasive action of tire chains than tightly closed surfaces would have been.

TENTATIVE CONCLUSIONS

At Completion of Construction Program

Following the construction of the Kentucky test sections the following tentative conclusions were included in a comprehensive report (CWR 700-16) submitted by Curtiss-Wright to the Kentucky Department of Highways:

1. The Kentucky experiments confirmed tentative conclusions reached at Quehanna that Kentucky coals from either the eastern or western coal areas of the State can be digested (dispersed) easily in coal tar or in a mixture of coal tar and tar oils with relatively simple equipment and without using manufacturing procedures requiring pressure or reflux conditions.

2. Curtiss-Wright binders made in 1,500-gal batches and hot mixes made therefrom at commercial hot-mix plants had characteristics substantially the same as binders and hot mixes made in the laboratories at Quehanna with Kentucky raw materials.

3. No major difficulties were encountered in the use of the Curtiss-Wright binders at hot-mix plants or in the laying of mixes made therefrom with standard paving equipment and procedures. However, the importance of avoiding contamination of the Curtiss-Wright binders with asphalt or with petroleum oils such as diesel oil, fuel oil, or kerosene was emphasized by sludging that occurred at a few of the plants. In

each case the first batch of hot mix was contaminated and sometimes had to be replaced.

4. Contrary to expectations that usual aggregate binder and mix temperatures specified for asphalt (225 to 325 F) could be used for Curtiss-Wright binders, it was decided because of somewhat excessive fuming during paving operations that the maximum temperature of the hot-mix at the paver should be limited to 260 F. Owing to the fact that hot mixes made with coal-tar binders can tolerate higher moisture contents in the dried aggregates and because coal-modified tar binders have lower viscosities than asphalt cements both at mixing and paving temperatures, this temperature limitation (260 F) should not cause any difficulties in either the mixing or the paving operations.

5. Hot-mixes made with Curtiss-Wright binders appeared to harden (set up or firm up) more rapidly than asphalt hot mixes, especially in hot weather. This permitted faster rolling and quicker opening of newly paved surfaces to traffic. This superiority for Curtiss-Wright mixes might not have been expected inasmuch as they contained the same proportions of binder, by volume, as the asphalt mixes. Also because the viscosities of the Curtiss-Wright binders are lower at paving and rolling temperatures than those of asphalt cements. The faster set-up was probably due to the greater penetration of Curtiss-Wright binders into and between the coarse and fine aggregates of which the hot mixes are chiefly composed. This is also believed to be the reason for the greater stabilities of Curtiss-Wright hot mixes that were observed in both the laboratory and the field investigations.

After One Year of Service

Six months after completion of the Kentucky test sections and again at the end of one year several were inspected for Curtiss-Wright by the author with representatives of the Kentucky Highway Research Department. The following observations were reported: Each of the Curtiss-Wright test pavements was too rigid, especially in the winter, for use over old bituminous plant and road-mix surfaces on weak underlying bases and subgrades. In hot weather the extra rigidity, as evidenced by a rapid firming-up of the hot mix, which permitted the rollers to operate close to the pavers, had been found to be advantageous, but in cold weather the extra rigidity did not permit the test pavements to follow the movement of underlying bases and subgrades with the result that cracking occurred. This was noticed particularly on test sections where, after pre-paving surveys, the Curtiss-Wright field engineer had reported very extensive maintenance of the old surfaces on which the test overlays were to be applied. Edge cracks, shrinkage cracks, open joints, and weak places in the old pavements apparently reflected through the new overlays containing Curtiss-Wright binders and they were not sufficiently self-healing to close the breaks and cracks during warm weather.

To provide more flexibility in pavements containing coal-modified tar binders the following were apparent:

1. A higher binder content should have been used in each case. Optimum binder content for maximum Marshall stability was the standard used in the Curtiss-Wright investigations but inspection of test data indicated that, at the Marshall optimum, aggregate voids were not filled as completely as they should have been. It appeared that about 7.5 percent of binder (by weight) should have been used instead of the specified 6.9 or 7.0 percent.

2. The coal-modified tar binders should have had lower softening points and higher penetrations. Their softening points were similar to those of asphalts used in the control sections for comparative purposes but, at the same softening points, coal-digestion binders have appreciably lower penetrations. It appears, therefore, that in future experiments of this kind penetrations rather than softening points should be used as the criteria for coal-digestion binder formulations, and penetrations substantially higher than those of the binders used in Kentucky should be specified when a high degree of flexibility and self-healing is required.

3. Storage, mixing, and paving temperatures should be maintained between about 200 and 250 F. At equal temperatures the viscosities of the Curtiss-Wright binders

are appreciably lower than those of paving asphalts; for the same time of mixing, it should not be necessary to use as high aggregate and binder temperatures as are employed with asphalt binders. Furthermore, experience has shown that binders containing coal tars can be used satisfactorily with aggregates containing higher amounts of moisture than are usable with asphalt cements. It is possible that the high aggregate and mixing temperatures which prevailed at times during the use of the Curtiss-Wright binders in Kentucky may have contributed to the excessive hardness of the test pavements, but it is more likely that the factors previously mentioned were largely responsible for it. However, the use of lower temperatures would minimize fuming of the binder which, although not injurious to health, can be annoying and should be avoided as much as possible.

RESUMPTION OF QUEHANNA LABORATORY INVESTIGATIONS

Following completion of the Kentucky pilot plant and field investigations in November 1959, laboratory investigations were resumed by Curtiss-Wright at Quehanna with a view to making further improvements in the formulation and use of hot-mix binders of the coal-dispersion types. During a period of approximately one year several studies were conducted.

Comparative Viscosities of Coal Tar, Coal Digestion and Asphalt Hot-Mix Binders

Representative samples of RT-12, CW III, CW II, and Asphalt Cement (PAC) from the Kentucky operations were tested for viscosity at various temperatures with a Brookfield viscosimeter. Table 10 gives the sources, softening points, and absolute viscosities of the various samples at 140, 225, 260, and 300 F. The viscosities of the various binders are also compared by means of curves in Figure 8.

It is apparent that the RT-12 had much lower viscosities at all temperatures between 140 and 300 F than coal dispersions of the types that were produced in the Kentucky pilot plant or asphalt cement (PAC) of the kind used in hot-mix, hot-lay bituminous concretes by the Kentucky Highway Department.

Furthermore, the coal-modified tar binders had viscosities appreciably lower than the Kentucky PAC binder. Therefore, for the same time of mixing, it should not be necessary to use as high aggregate and binder temperatures at hot-mix plants when coal-modified tar binders are employed instead of asphalt cements.

Coal Sources and Properties vs Characteristics of Coal Dispersions

Samples of 17 eastern and 9 western Kentucky coals were analyzed separately and tested individually for their digestibility or dispersibility in RT-12 by a laboratory flask method developed at Quehanna. It was performed in the following manner:

TABLE 10

COMPARATIVE ABSOLUTE VISCOSITIES AT VARIOUS TEMPERATURES OF ASPHALT, RT-12 AND COAL-MODIFIED RT-12 BINDERS WITH AND WITHOUT HIGH-BOILING COAL-TAR OIL

Property	RT-12	CW-II	CW-III	CW-III	PAC
Binder source	London US 25	Ky. plant batch 102	Ky. plant batch 85	Ky. plant batch 6	Ky. Highway Depart.
Softening pt. (R & B) (°C)	35.9	47.0	43.2	46.6	48.6
Absolute viscosity (CP):					
140 F	15,890	60,500	79,700	141,500	317,500
225 F	224	1,150	1,870	2,195	5,040
260 F	96	364	647	719	1,150
300 F	58	155	332	348	400

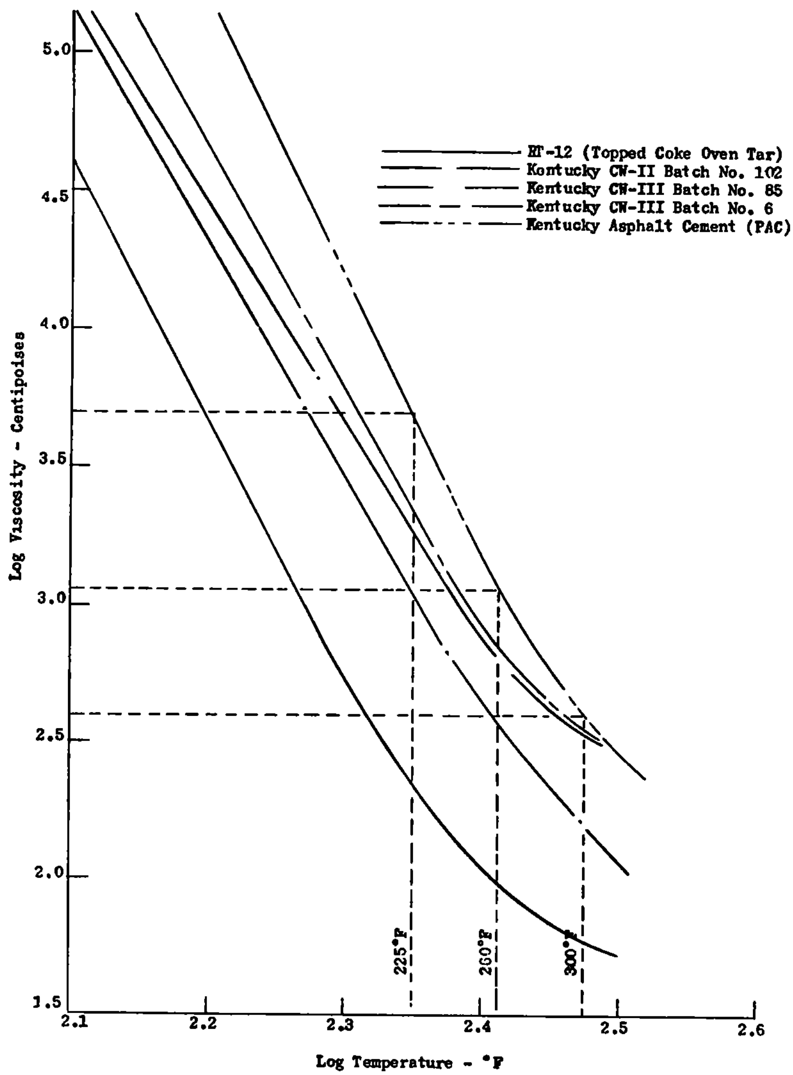


Figure 8. Log viscosities vs log temperatures for typical samples of five hot-mix binders used in Kentucky highway test sections.

A portion of the coal sample to be tested was pulverized to pass a 100 mesh sieve and dried to constant weight. A 25-g sample of the dry, pulverized coal was then introduced into a 500 ml, three-neck balloon flask containing 225 g of distilled high-temperature coke-oven tar meeting AASHO (M 52-42) specification requirements for RT-12 grade road tar. By means of an electric heating mantel controlled by a rheostat the tar-coal mixture was heated to 600 F and held at that temperature under reflux and with continued agitation for one hour. After cooling to approximately 400 F it was poured into standard containers for ASTM (D 5-52) penetration tests and into standard brass rings for ASTM (D 36-26) ring and ball softening point determinations. By using four assemblies it was possible to test four coal samples simultaneously. Each finished dispersion was tested for softening point (ring and ball) and penetration (100 g - 5 sec) at 25 and 32 C. The average analyses of the 17 eastern and 9 western coals are given in Table 11.

Average softening points and penetrations of coal dispersions made from the same samples by the methods described are given in Table 12 and shown by the two curves

TABLE 11

AVERAGE ANALYSES OF SEVENTEEN EASTERN AND NINE WESTERN KENTUCKY COALS

Coal Source	Coal No.	Moisture (%)	V. M. (%)	F. C. (%)	Ash (%)	S (%)	F. S. Index
Eastern Ky.	17	2.78	36.63	57.62	5.70	0.79	3.6
Western Ky.	9	5.66	38.84	52.86	8.31	2.83	3.2

TABLE 12

AVERAGE SOFTENING POINTS AND PENETRATIONS FOR 10 PERCENT DISPERSIONS IN RT-12 OF SEVENTEEN EASTERN AND NINE WESTERN KENTUCKY COALS

Coal		S. P.	Pen. (100g/5 sec)		Log Pen. (100 g/5 sec)	
Source	No.	R & B	At 25 C	At 32 C	At 25 C	At 32 C
Eastern Ky.	17	54.3	29.5	81.5	1.441	1.876
Western Ky.	9	60.4	18.9	45.3	1.261	1.724

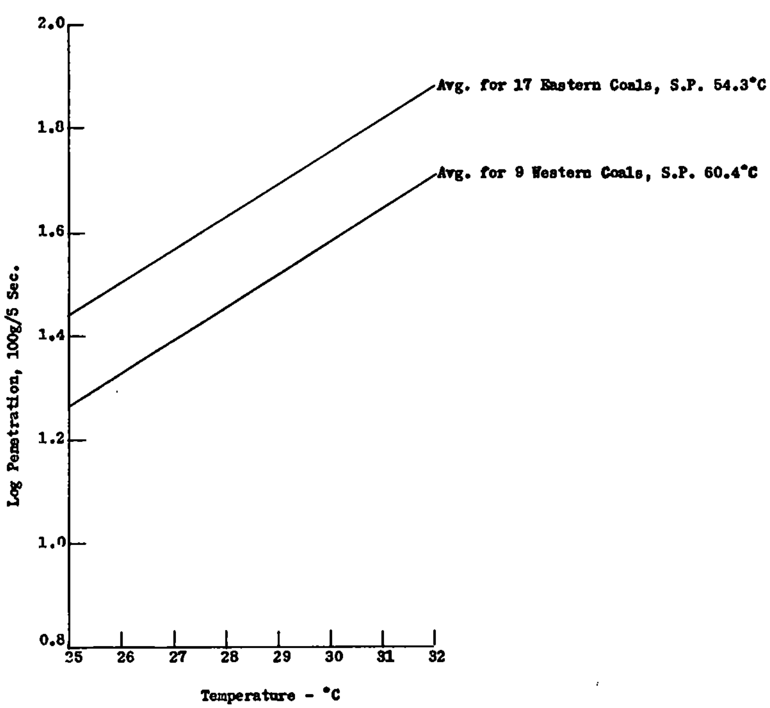


Figure 9. Comparative log penetration-temperature relationships for average eastern and western Kentucky coal dispersions in RT-12.

in Figure 9. The fact that the two curves are substantially parallel indicates that eastern and western Kentucky coals, when used in equal amounts with RT-12, produce coal dispersions having equal temperature susceptibilities but the western coals have a greater effect on softening point than the eastern coals. On the average, 10 percent of western coal raised the softening point of the RT-12 about 26 C, whereas the increase for eastern coal was about 20 C.

The softening points and temperature susceptibilities (log Pen. 100 g - 5 sec vs Temp. C) of dispersions made in the previously described manner with coals from various sources are compared in Figure 10 with each other and with the eastern and western Kentucky coals. The sources of the coals, number of samples tested from each source, and the average softening points (R & B) of their dispersions in RT-12 are given in Table 13. The Alabama coal produced the smallest increase in softening point and Indiana coal the greatest. Kentucky, Pennsylvania, and Oklahoma coals were intermediate between those two.

It is also apparent from Figure 10 that the coals from all eight sources produced dispersions having substantially equal temperature susceptibilities and they all had temperature susceptibilities like that of the original RT-12. In other words, it appears from these data that bituminous coals, regardless of source do not change the temperature susceptibility in the temperature range of 25 to 32 C of a given soft pitch (RT-12) derived from high temperature coke-oven tar but the softening points of coal dispersions made by digesting 10 percent of coal in the RT-12 vary by substantial amounts depending on the source of the coal.

The log-penetration-softening point relationships for 23 coal samples from 10 different locations in North and South America and from Japan are shown in Figure 11. Although the various coals produced dispersions with widely varying softening points

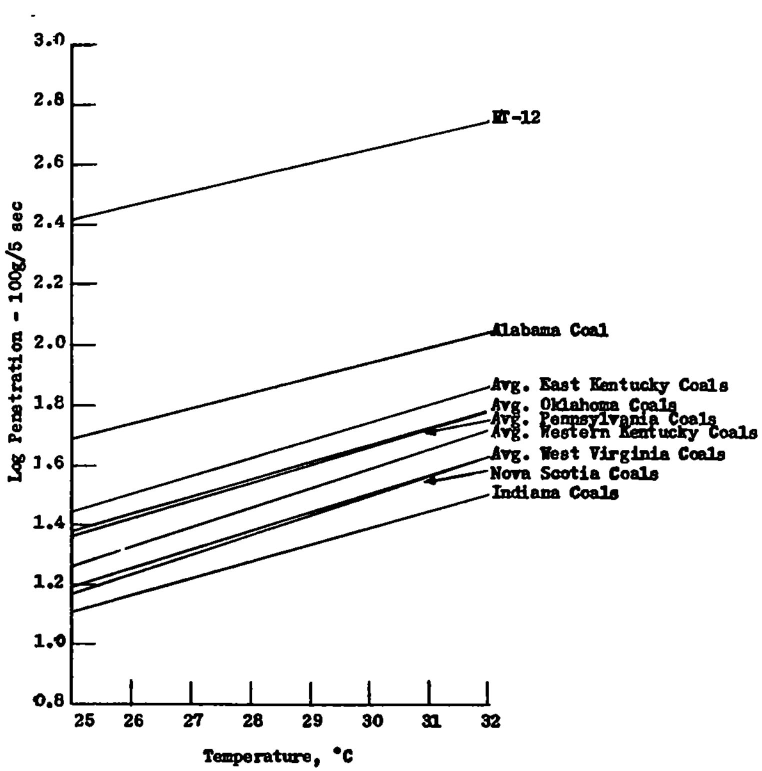


Figure 10. Comparative log penetration-temperature relationships for dispersions made with coals from various sources.

TABLE 13

NUMBERS OF COAL SAMPLES TESTED FROM VARIOUS SOURCES AND AVERAGE SOFTENING POINTS OF THEIR 10 PERCENT DISPERSIONS IN RT-12

Coal Source	No. of Samples	Avg. S. P. of Dispersions (°C)
Alabama	1	48.8
East Kentucky	17	54.3
Oklahoma	8	58.3
Pennsylvania	2	52.5
West Kentucky	9	60.4
West Virginia	3	58.7
Nova Scotia	1	57.4
Indiana	1	66.0

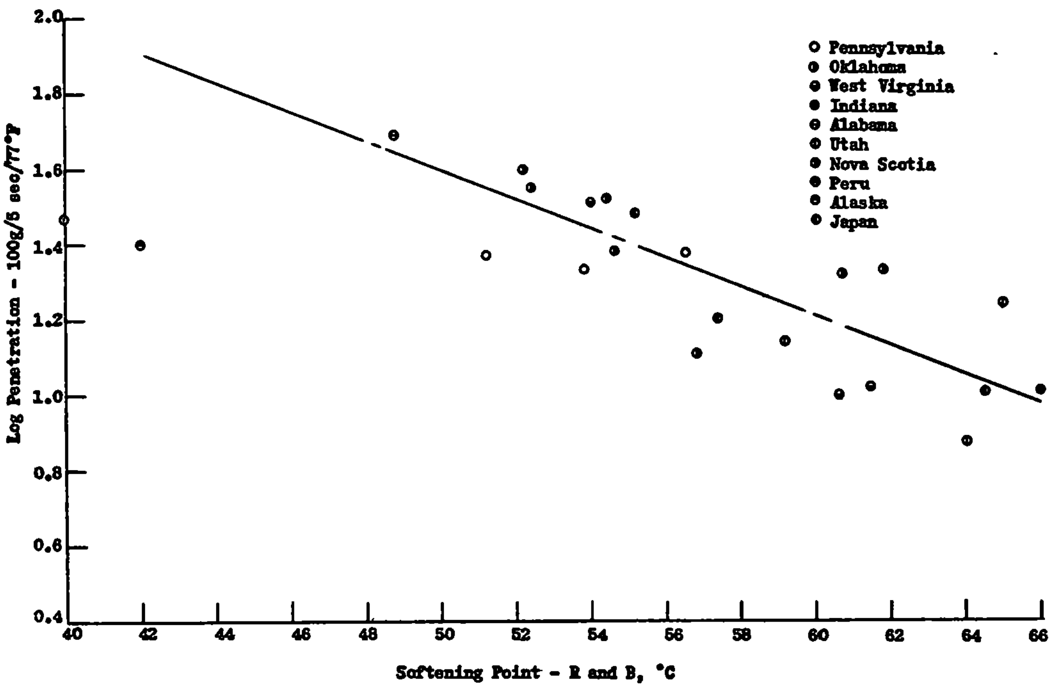


Figure 11. Comparison of penetration-softening point relationships for coal dispersions made with coals from various sources.

(40 to 65 C) and log penetrations (0.9 to 1.7), all of them, with the exception of the Alaskan and Peruvian coals, seemed to exhibit similar penetration-softening point relationships.

Attempts to correlate these various relationships with coal analyses have not led to any satisfactory conclusions.

Suitability of Different Coal Tars for Coal Dispersions

In most of the investigations conducted at Quehanna and in all of the pilot plant operations in Kentucky, topped high-temperature, coke-oven tars meeting ASTM specifications for RT-12 road tar were used either alone or in combination with high-boiling coal-tar oil as the digesting medium for bituminous coal.

However, a few tests were performed to determine whether other types of coal tar might be employed instead of high-temperature tars. Samples tested were as follows:

1. Low-temperature coal tar produced experimentally by the U.S. Fuel Company, Salt Lake City, Utah, with the Craiglow process. The softening point (R & B) of the sample as received was 44.3 C.
2. Low-temperature coal tar produced experimentally by the U.S. Smelting, Refining and Mining Company, Salt Lake City, Utah. Before mixing with coal for digestion the crude tar was topped to a softening point of 41.7 C (R & B).
3. Medium-temperature tar made by Curtiss-Wright in connection with carbonization experiments which produced a medium-temperature crude tar having the following characteristics (dehydrated): specific gravity 25/25 C, 1.1183; specific viscosity, Engler at 50 C, 65.3; distillation to 170 C, 0.0 percent; to 235 C, 6.3 percent; to 270 C, 17.3 percent; to 300 C, 36.1 percent; softening point of distillation Res. (R & B), 70.7 C. Before digestion with coal, this tar was topped to a softening point of 36.6 C (14.2 percent distillate removed).
4. High-temperature, coke-oven tar topped to RT-12 (34 C) from Koppers Company, USA.
5. High-temperature coke-oven tar from Tosho Ltd., Japan, topped to 33.5 C by Curtiss-Wright.
6. High-temperature coke-oven tar from Dominion Steel and Coal Corporation, Nova Scotia, topped to 40.6 C.

Each of these tars was mixed with 10 percent by weight of Kentucky Alma seam coal and digested by the Curtiss-Wright laboratory flask method previously described. As shown by Figure 12, in which log penetration (100g, 5 sec, 25 C) is plotted against increase in softening point, the three high-temperature coke-oven tar dispersions increased about equally and to the greatest extent; an appreciable increase occurred in the case of the medium-temperature tar, but very little increase accompanied the use of either of the two low-temperature tars.

Although preliminary in nature and limited in scope, the tests described support opinions previously advanced that true low-temperature tars without modification or special procedures are not as suitable as high-temperature or medium-temperature coal tars for making coal dispersions.

Another series of tests was performed to compare two- and three-component dispersions made from Disco tar with the 70-85 penetration asphalt and with the two- and three-component binders CW III and CW II made with distilled high-temperature coke-oven tar (RT-12). Disco tar, produced by Consolidation Coal Company at Champion, Pa. is usually referred to as a low-temperature tar but its characteristics more nearly resemble those of medium-temperature tars (22). The test data for the five binders are given in Table 14 and their log-penetration-temperature relationships in the range of 25 to 32 C are shown in Figure 13. They indicate that the temperature susceptibility of the three-component binder containing topped Disco tar (pitch) is substantially the same as that of the 70-85 asphalt cement, somewhat better than the binders containing RT-12, and appreciably better than the two-component binder containing Disco pitch. From the standpoint of adhesion to aggregates (aqueous stripping) the Disco three-component binder was superior to the asphalt cement and equal to the CW-III binder containing RT-12. The jet fuel solubility of the Disco CW-III binder was much better than that of the asphalt cement but not quite as good as that of the CW-III binder containing RT-12. Summarizing, the binder made with Disco pitch, coal, and high-boiling coal-tar oil had practically the same temperature susceptibility as the asphalt, was much better than the asphalt with respect to water stripping and petroleum oil solubility, but was not quite as good in the latter respect to binders made with distilled high-temperature coke-oven tar (RT-12).

Comparative data for Marshall stability, flow, impact, loss on heating, and change in stability after immersion in water are given in Table 15 for the three-component binder made with RT-12, the three-component binder containing Disco pitch, and the 70-85 penetration asphalt cement.

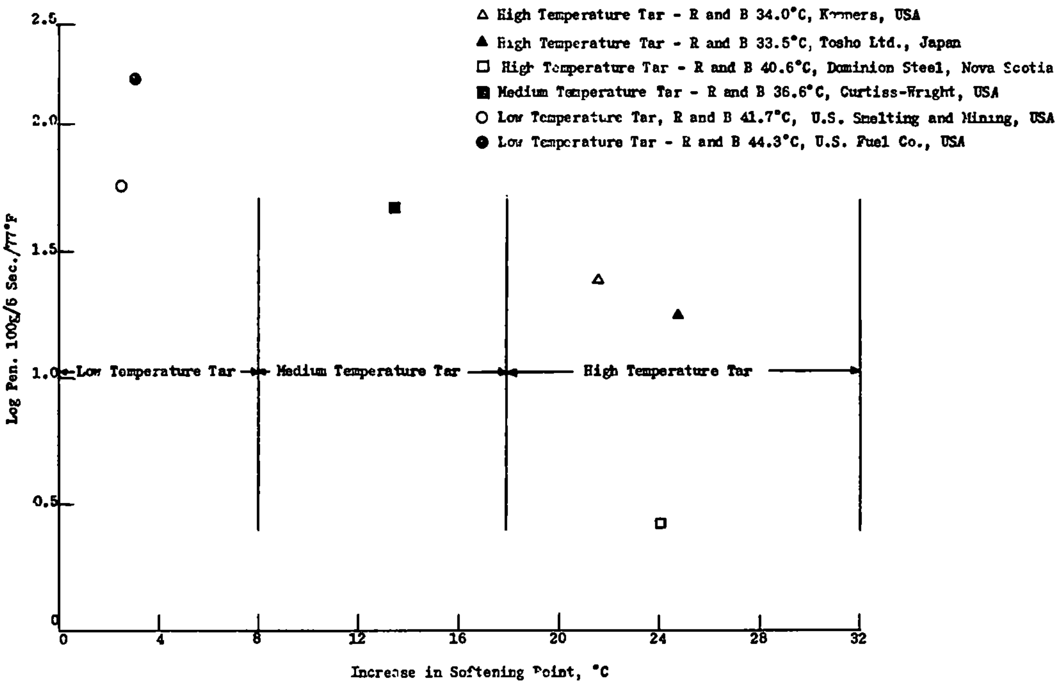


Figure 12. Effects of different tars on properties of coal digestion products containing 10 percent Kentucky (Alma seam) coal.

TABLE 14

COMPARATIVE TEST RESULTS FOR TWO- AND THREE-COMPONENT DISPERSIONS CONTAINING DISCO PITCH, TWO- AND THREE-COMPONENT DISPERSIONS CONTAINING RT-12, AND 70-85 PENETRATION ASPHALT

Property	Binder				
	Disco CW-II	RT-12 CW-II	Disco CW-III	RT-12 CW-III	Asphalt
Binder No.	96-132-1	96-67-1	96-92-1	96-79-1	13-111-1
Composition (%)					
Disco pitch 41.5 C	96.0	-	64.4	-	--
RT-12	--	89.2	--	64.4	--
Coal	4.0	10.8	11.4	11.4	--
H.-b. coal-tar oil	--	--	24.2	24.2	--
70-85 pen asphalt	--	--	--	--	100
Softening pt., R & B (°C)	48.5	50.8	49.0	45.5	51.8
Specific gravity	1.183	1.255	1.225	1.242	1.030
Penetration:					
50 g/5 sec/25 C	32.0	28.6	54.3	43.8	50.1
50 g/5 sec/32 C	75.0	61.5	104.5	91.5	93.3
100 g/5 sec/25 C	45.2	38.0	87.5	65.3	71.0
100 g/5 sec/32 C	118.8	79.0	157.8	129.3	143.0
Aqueous stripping (%)	--	14.0	0	0	47.0
JP-4 solubility	25.3	12.3	31.5	17.1	93.2

1	64.4 Disco Pitch, 11.4 Coal, 24.2 H.B.Oil S.P.	49.0
2	70-85 Penetration Asphalt	51.8
3	64.4 RT-12, 11.4 Coal, 24.2 H.B.Oil (CW III)	45.5
4	96.0 Disco Pitch, 4.0 Coal	48.5
5	89.2 RT-12, 10.8 Coal (CW-II)	50.8

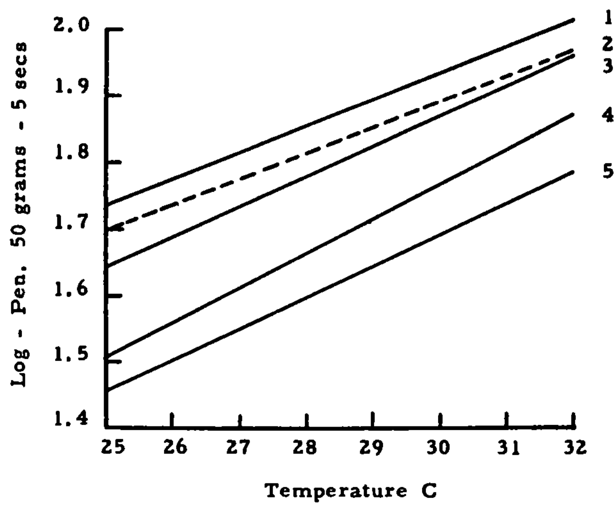


Figure 13. Temperature susceptibility curves for asphalt, coal-modified RT-12 with and without high-boiling coal-tar oil and coal-modified disco pitch with and without high-boiling oil.

Briquets made with the binder containing Disco pitch, coal, and high-boiling coal-tar oil had the highest Marshall stabilities and lowest flow numbers. Their impact resistances at 32 and 77 F, loss on heating for 72 hr at 140 F, and change in stability after water immersion for 96 hr at 120 F were intermediate between those of the briquets made with binders containing asphalt cement or the coal-modified tar binder containing RT-12, coal, and high-boiling oil.

Addition of Polymers to Coal-Modified Tar Binders

Inspired in part by tests reported in October 1959 by Karius and Dickinson (23), experiments were performed with a view to making further improvements in coal-digestion binders by the admixture of polymers. The following materials were used: Hycar latex No. 1577; natural rubber latex X3B; butyl rubber (toluol solution); Vistanex (toluol solution); reclaimed rubber (powdered); neoprene latex No. 750; neoprene powder, PB; Thiokol LP-3.

Admixtures of these materials were made in proportions up to 2.0 percent with a CW III hot-mix binder containing 78.9 percent RT-12; 7.2 percent coal and 13.9 percent high-boiling coal-tar oil. The softening point of the CW III was 48.2 C.

To prepare the mixtures, except those containing butyl and Vistanex, a quantity of the CW III was weighed into a beaker, heated to 300 F with agitation on a hot plate, and the desired amount of additive required to equal 0.25; 0.5; 1.0; or 2.0 percent of pure polymer was added slowly. The temperature was held at 300 F, and agitation was continued until the mixture appeared to be homogeneous. It was then poured into molds and containers for softening point, penetration, and loss on heating tests.

TABLE 15

COMPARATIVE TESTS ON MARSHALL HOT-MIX BRIQUETS CONTAINING ASPHALT, DISPERSION OF COAL IN RT-12, AND H. B. COAL-TAR OIL, AND A DISPERSION OF COAL IN DISCO (MED. TEMP. TAR) PITCH AND H. B. COAL-TAR OIL

Property	Binder in Hot Mix		
	CW-III (RT-12)	CW-III (Disco)	Asphalt
Composition (% by wt):			
Disco pitch (41.5 C)	--	64.4	--
RT-12	64.4	--	--
Coal	11.4	11.4	--
H.-b. oil	24.2	24.2	--
Asphalt	--	--	100
Binder softening pt	45.4	49.0	51.8
Binder content at optimum	5.9	5.5	5.0
Marshall stability at optimum	3,344	3,490	2,326
Marshall flow at optimum	11.0	8.5	17.4
Impact test at optimum:			
At 32 F	19.0	22.3	23.0
77 F	23.0	23.3	28.0
Loss on heating, 72 hr at 140 F	0.6	0.58	0.04
Impact after heating test:			
At 32 F	28.0	23.3	17.0
77 F	33.0	22.0	46.0
Change in stability after water immersion for 96 hr at 120 F (%)	+88	--	-17

To introduce the butyl rubber and Vistanex samples into the CW III binder they were first dissolved in toluol to make a 25 percent solution. The latter was then added slowly with agitation to a weighed amount of CW III that had been heated only to fluidity. After all of the toluol solution had been added, the temperature of the mixture was raised to 300 F and held there with agitation until the mixture appeared to be uniform. No difficulties were encountered in preparing any of the mixtures. Following are brief discussions of the test results which are given in Tables 16 and 17.

Loss on Heating. Each of the mixtures was subjected to the standard ASTM loss on heating test at 325 F for 5 hr. Also for comparison, samples of the original CW III binder and of the Pennsylvania 70-85 penetration asphalt cement were tested in the same manner. Inspection of the test data shows that the loss on heating was decreased somewhat by each of the polymers but the largest decreases occurred with those samples in which non-uniformity or crusting developed during the heating period. However, in no case was the loss on heating decreased to the level of the 70-85 asphalt.

Effect on Softening Point and Penetration. Each of the polymers increased the softening point of the CW III to some extent both before and after heating for 5 hr at 325 F. Reclaimed rubber, Vistanex, and Thiokol had the smallest effects and the two neoprenes the highest. Natural rubber latex, Hycar latex, and butyl rubber were intermediate in this respect.

The rate of decrease in penetration at 77 F with increase in softening point was greatest in the cases of reclaimed rubber and Vistanex and least with Thiokol, natural rubber latex, and neoprene powder. Neoprene latex, butyl rubber, and Hycar latex were intermediate. At penetration 40 (100 g, 5 sec, 77 F) the softening points of the

TABLE 16

CHARACTERISTICS OF 70-85 PEN ASPHALT CEMENT, CW-III HOT-MIX BINDER AND POLYMER-MODIFIED CW-III BINDERS BEFORE AND AFTER HEATING FOR 5 Hr AT 325F

Material Tested	Loss	Soft Pt (R-B)		Pen 200/60/32 F		Pen 100/5/77 F		Pen 50/5/115 F		Suscept Factor		Uniform Condition	
	(%)	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Reference material													
Pa 70/85 asphalt cement	0 08	49 8	51 7	28 3	20 9	63 0	56 6	303	--	4 4	--	Yes	Yes
CW-III hot-mix binder	2 12	48 2	55 4	28 3	5 5	55 0	21 5	230	131	3 5	5 9	Yes	Yes
CW-III modified with Hycar (Latex 1,577)													
0 5%	1 73	50 6	56 3	13 5	0 0	40 1	4 0	276	--	6 5	--	Yes	No
1 0%	1 44	52 8	57 5	12 8	0 0	30 5	2 5	185	--	5 6	--	Yes	No
2 0%	1 56	55 4	60 0	12 2	--[1]	26 3	--[1]	158	--	5 5	--[1]	Yes	--[1]
Nat rubber (Latex X2B)													
0 5%	2 16	51 7	55 6	19 5	0 0	48 8	5 0	328	36 2	6 2	7 2	Yes	No
1 0%	2 13	51 6	54 2	26 8	5 0	53 6	18 3	318	50 5	5 4	2 5	Yes	No
2 0%	1 46	56 4	56 8	15 0	0 0[1]	34 5	0 0[1]	135	21 0[1]		--	Yes	--[1]
Butyl rubber (toluol soln)													
0 5%	1 64	50 4	57 4	11 5	1 2	42 7	21 0	265	129	5 9	6 3	Yes	Yes
1 0%	1 58	47 6	56 2	20 2	15 0	47 9	36 1	333	--	6 5	--	Yes	Yes
Vistanex (toluol soln)													
0 5%	1 89	46 2	55 0	24 5	6 0	62 7	34 2	399	143	5 9	4 0	Yes	Yes
1 0%	1 56	49 0	55 4	18 7	6 0	44 7	20 3	295	62	6 1	2 8	Yes	Yes
Reclaim rubber (Crumb) (2 0%)	1 36	48 8	53 0	18 7	1 5	45 5	3 8	330	--	6 8	--	Yes	No
Neoprene (Latex 750)													
0 25%	2 40	48 8	57 0	16 5	0 0	46 3	24 6	314	109	6 4	4 4	Yes	Yes
0 5%	2 41	52 8	57 8	15 7	8 0	39 7	25 8	240	123	5 6	4 5	Yes	No
1 0%	1 79	55 4	61 0	13 7	1 0	31 0	3 5	175	--	5 2	--	Yes	No
2 0%	1 28	58 0	65 2	15 0	Crust	32 3	--[1]	152	--[1]	4 2	--[1]	Yes	--[1]
Neoprene (P B Powder)													
0 5%	1 97	54 8	60 6	15 8	0 0	29 7	10 5	177	51 3	5 2	4 9	Yes	No
1 0%	1 71	57 5	58 8	18 2	0 0	35 0	1 5	185	--	4 8	--	Yes	No
2 0%	1 51	66 2	63 6	14 3	3 0[1]	27 6	0 0[1]	125	3 3[1]	4 1	--	Yes	--[1]
Thiokol (LP-3)													
0 5%	2 80	50 2	54 0	20 7	7 0	50 1	38 5	371	158	6 9	3 9	Yes	Yes
1 0%	1 98	49 3	55 4	18 2	3 8	45 8	25 8	365	150	7 5	5 7	Yes	Yes
2 0%	1 96	49 6	65 1	20 3	5 0	51 7	26 0	352	--	6 4	--	Yes	Yes

[1]Hard crust

TABLE 17

SUMMARY OF TEST RESULTS FOR ASPHALT AND CW-III TYPE BINDER MODIFIED WITH 1 PERCENT OF VARIOUS POLYMERS

Material	Polymer	Loss at	Soft Point (°C)		Suscept Fact		Uniform		Benson Tests at 77°F	
	(%)	325 (%) F	Before	After	Before	After	Before	After	Peak (lb)	Elong (in)
70/85 penetration asphalt	0	0 08	49 8	51 7	4 4	--	Yes	Yes	--	--
CW-III hot-mix binder										
alone	0	2 12	48 2	55 4	3 5	5 9	Yes	Yes	56	8 5
with Hycar Latex 1577	1	1 44	52 8	57 5	5 6	--	Yes	No	194	6 0
with Nat rubber Latex X2B	1	2 13	51 6	54 2	5 4	2 5	Yes	No	130	--
with butyl rubber	1	1 58	47 6	56 2	6 5	--	Yes	Yes	178	9 2
with vistanex	1	1 56	49 0	55 4	6 1	2 8	Yes	Yes	137	9 4
with reclaimed rubber	2	1 36	48 8	53 0	6 8	--	Yes	No	77	6 8
with neoprene Latex 750	1	1 79	55 4	61 0	5 2	--	Yes	No	207	1 8
with neoprene powder PB	1	1 71	57 5	58 8	4 8	--	Yes	No	>240	0 0
with Thiokol LP-3	1	1.98	49 3	55 4	7 5	5 7	Yes	Yes	94	16+

mixtures were as follows: reclaimed rubber, 49.2 C; Vistanex, 49.5 C; Hycar latex, 50.5 C; butyl rubber, 51.2 C; neoprene latex, 52.5 C; natural rubber latex, 55.3 C; Thiokol, 56.0 C; neoprene powder, 56.0 C.

Temperature Susceptibility. The temperature susceptibility factor for each mixture before and after the loss on heating test is shown in Table 17, calculated as follows:

$$\text{Temperature susceptibility factor} = \frac{\text{Pen } 50/5/115\text{ F} - \text{Pen } 200/60/32\text{ F}}{\text{Pen } 100/5/77\text{ F}}$$

On this basis it appears that the temperature susceptibility of the original CW III was slightly better than that of the 75-85 asphalt but the temperature susceptibilities of all of the mixtures containing polymers were higher (poorer) than that of the asphalt and of the original CW III. Similar factors could not be calculated for some of the mixtures after heating because of non-uniformity or crusting that interferred with penetration tests.

Benson Tests. All the polymer admixtures were tested by a method devised by Jewell R. Benson (24) in which the peak force required to pull a 7/16-in. diameter polished metal, hemispherical tension head from a sample of the bituminous material is determined at 77 and 115 F. Also the elongation at time of rupture is measured. All the polymers increased the peak force required to remove the tension head from the specimen both at 77 and 115 F. The greatest increase at 77 F was caused by neoprene powder PB and next to the least by Thiokol. The reverse was true for elongation (inches) at 77 F. Thiokol gave the greatest increase in elongation and neoprene powder the lowest. In other words, neoprene powder made the CW III tougher but less ductile at 77 F whereas Thiokol gave a smaller increase in toughness but greater improvement in ductility at 77 F. The only other samples which showed an improvement in elongation (ductility) were Vistanex and butyl rubber. They increased the toughness peak of the CW III at 77 F somewhat more than the Thiokol.

Summary of Polymer Test Results. Only the butyl, Vistanex, and Thiokol admixtures remained uniform after the loss on heating test (325 F for 5 hr) and of these three the results with the Vistanex admixture appeared to be the most promising. The decrease in temperature susceptibility factor from 6.1 to 2.8 on heating at 325 F for 5 hr is particularly noteworthy and should be confirmed by additional investigations. In fact, additional tests with butyl rubber, Vistanex, and Thiokol should be made to determine how they might be used most advantageously.

Use of Fluxes Other Than High-Boiling Coal-Tar Oil in Coal Dispersions

Throughout all of the experimental work at Quehanna and pilot plant operations at Frankfort, high-boiling coal-tar oil was used as a flux or plasticizer in coal dispersions of the three-component type (CW III).

The possibility of using petroleum oils as fluxes instead of high-boiling coal-tar oil was investigated to a limited extent. Samples were obtained from the Gulf Oil Corporation and Esso Oil Corporation which were thought to have possibilities in this connection. Two oil samples from Gulf Oil Corporation were designated as Port Arthur decanted oil and furfural extract, respectively. A sample from Esso was labeled No. 11 flux.

For comparison with a three-component dispersion containing high-boiling coal-tar oil, similar dispersions were made with each of the petroleum oils by adding it to a two-component binder containing 90 percent RT-12 and 10 percent coal whose softening point was 55 C. For each mixture containing petroleum oil, the oil and the two-component dispersion were heated separately to 250 to 260 F and the oil was added slowly to the coal dispersion. Vigorous agitation was continued until the mixture appeared to be homogeneous. Portions of the mixture were then tested for ring-and-ball softening point, loss on heating, penetration, and Benson toughness peak and elongation tests. The data obtained from these tests are summarized in Table 18. A critical analysis of the data and examination of each of the samples before and after the loss-on-heating tests led to the following conclusions.

Compatability. When the various three-component mixtures were subjected to the loss-on-heating test (5 hr at 325 F), the mixture containing high-boiling coal-tar oil was the only one that remained homogeneous. Each of the others became non-uniform and those containing decanted oil developed hard crusts.

Fluxing Capacity. From the softening points and flux contents of each of the mixtures containing petroleum oil, it was calculated that the amount of each oil required to reduce the softening point of the CW II (55.0 C) to that of the CW III (48.2 C) would be as follows: Esso No. 11 flux, 12.4 percent; decanted oil, 7.4 percent; and furfural extract, 4.9 percent. Because the three-component binder (with the same softening point) contained 13.8 percent of high-boiling oil, it appears that the decanted oil and furfural extract had considerably greater fluxing powers than the No. 11 flux or the high-boiling oil.

Temperature Susceptibilities. Several attempts were made to compare the various mixtures as to temperature sensitivity or susceptibility of consistency to temperature. As shown in Figure 14 a curve was plotted for each binder using its log penetrations at 0, 25, and 46 C (32, 77, and 115 F). On this basis, because of its flatter slope between 0 and 25 C, the coal-modified tar binder containing high-boiling coal-tar oil would appear to have a better temperature susceptibility in that range than the asphalt

TABLE 18

COMPARISON OF COAL-MODIFIED TAR BINDERS CONTAINING DIFFERENT FLUXES WITH UNFLUXED CW-II AND ASPHALT

Property	Binder					
	CW-II	CW-II with Esso #11 Flux	CW-II with Decant Oil Flux	CW-II with Furf. Extr. Flux	CW-II with H. B. Oil Flux	Asphalt
Composition (% by wt):						
RT-12	90.0	74.7	77.6	83.2	79.0	--
Coal	10.0	8.3	8.6	9.3	7.2	--
Flux	--	17.0	13.8	7.5	13.8	--
Softening point, R & B (°C)	55.0	45.7	42.7	45.4	48.2	49.8
Penetration:						
200 g/60 sec/32 F	9.6	25.3	54.2	38.2	28.3	28.3
100 g/5 sec/77 F	28.5	60.4	182.0	100.0	55.0	63.0
50 g/5 sec/115 F	139.0	299.0	--[a]	--[a]	230.0	303.0
Susceptibility factor	4.54	4.53	--	--	3.67	4.36
Penetration ratio	4.87	4.95	--	--	4.18	4.81
Penetration index	-1.2	-2.0	0 0	-1.0	-1.4	-1.0
Loss on heating, 5 hr, 325 F	2.69	1.22	3.53	3.39	2.12	0.08
Res. after heating, 5 hr, 325 F:						
Softening point (°C)	62.5	55.4	46.8	53.8	55.4	51.7
Pen. 200-60-32 F	0	0[b]	0[c]	11.8[b]	5 5	20.9
Pen. 100-5-77 F	14.3	0.1[b]	1 2[c]	44.0[b]	21.5	56.6
Pen. 50-5-115 F	65.0	25.0[b]	--[c]	16.3[b]	131.0	--[a]
Toughness peak-Benson (lb):						
At 77 F	123.6	54.0	18.5	24.0	56.0	36.0
115 F	8.0	2.5	1.3	2.2	1.6	2.2
Elongation-Benson (in.)						
At 77 F	9.4	0	7.3	7.5	8.3	16+
115 F	14.1	0	8.0	13.0	16+	16+

[a] Too soft.
[b] Non-uniform.
[c] Hard crust, sludge on stirring.

or any of the mixes containing petroleum fluxes. The superiority of the coal-modified binder with coal-tar oil also was indicated both on the basis of susceptibility factor and penetration ratio but from penetration indexes it would appear that the asphalt and coal-modified tar binder containing the furfural extract should have the best temperature susceptibilities. The methods for calculating susceptibility factors, penetration ratios, and penetration indexes were as follows:

$$\text{Susceptibility factor} = \frac{\text{Pen at 46.1 C (50g - 5 sec) (Pen at 0C (200 g - 60 sec)}}{\text{Pen at 25 C (100 g - 5 sec)}}$$

$$\text{Penetration ratio} = \frac{\text{Pen 46.1 C (50 g - 5 sec)}}{\text{Pen 25 C (100 g - 5 sec)}}$$

Penetration index was determined from a softening point/penetration nomogram (25).

In general, it appeared from the standpoint of temperature susceptibility that no improvement of coal-modified tar binders could be expected from the use of any one of the three petroleum oils tested.

Benson Tests. The coal-modified tar binder containing high-boiling coal-tar oil, at 77 F, had a toughness peak similar to that of the binder containing Esso No. 11 flux, somewhat higher than that of the asphalt cement, and considerably higher than the peaks for the binders made with decanted oil and with furfural extract. On the other hand, at 115 F the toughness peak of the coal-modified tar binder with high-boiling coal-tar oil was lower than any of the others with the exception of the binder containing decanted oil.

The elongation test results, at both 77 and 115 F, favor the asphalt cement with the coal-modified binder containing high-boiling coal-tar oil second, the Gulf oils

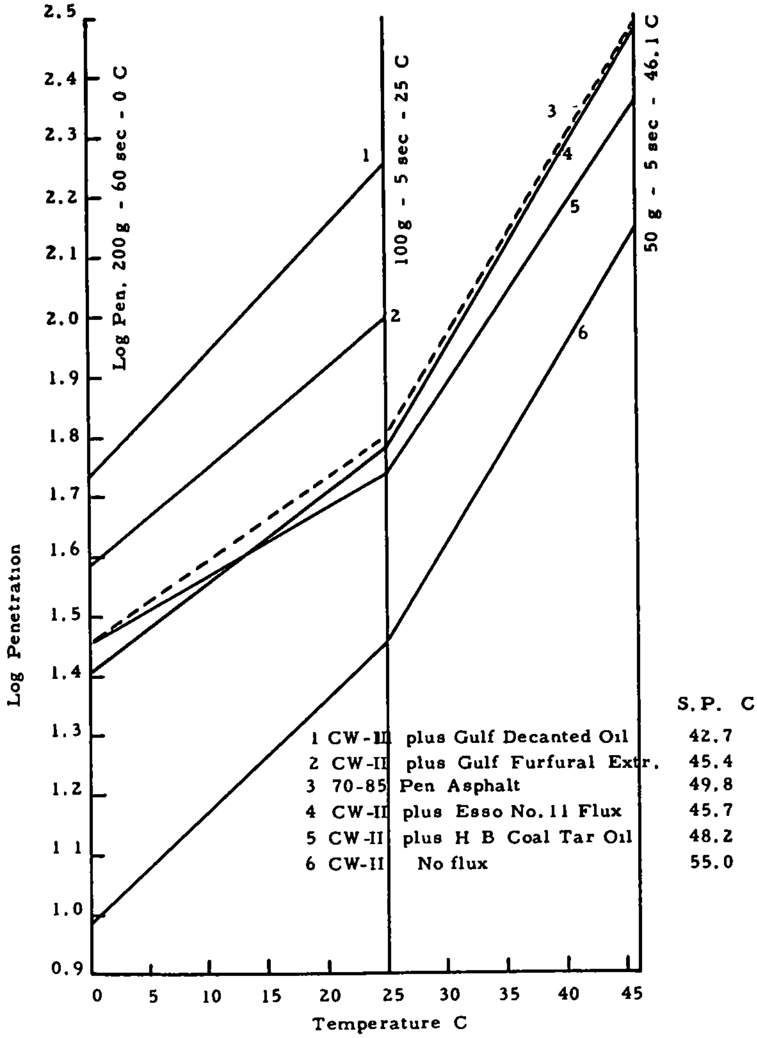


Figure 14. Temperature susceptibility curves for asphalt and coal-modified RT-12 plus various fluxing oils.

next, and the Esso No. 11 flux last. The fact that the samples containing the petroleum fluxes and particularly the Esso No. 11 flux had such poor elongations probably reflects incipient sludging in those samples which became more apparent after heating for 5 hr at 325 F in the loss-on-heating test.

Conclusions Regarding Petroleum Fluxes Tested. From the results of the foregoing tests it was concluded that none of the petroleum fluxes tested can be used as satisfactorily as high-boiling coal-tar oil as a flux for coal dispersions.

Addition of Soft Petroleum Asphalts to Coal Dispersions

A final attempt to effect further improvements in coal-modified tar binders, involving the use of soft petroleum asphalts, was started in December 1960 just before the termination of all work on coal-tar binders at Quehanna.

In the test, 72.4 percent of the coal-modified binder containing 90 percent of RT-12 and 10 percent coal was intimately mixed with 27.6 percent of 180-200 penetration asphalt furnished by Esso and said to have been produced by the straight distillation of an asphaltic base petroleum.

Using the same proportions, a second mixture was made in which asphalt from the same source but of 250-300 penetration was used.

Two other mixtures were prepared in each of which 27 percent of each of the previously mentioned asphalts was mixed with 5 percent of high-boiling coal-tar oil and 68 percent of the same coal-modified tar binder.

Each mixture was tested for softening point and penetration at 32, 77, and 115 F, with the results given in Table 19 which also includes comparative data for the 70-80 asphalt, CW II and CW III. Curves plotted from the penetration results given in Table 19 are shown in Figure 15. Of particular importance is the fact that between 0 and 25 C the log penetration-temperature curves for the two mixtures containing only coal, RT-12, and petroleum asphalt of either 180-200 or 250-300 penetration are substantially flat, indicating that by adding high-penetration residuals from asphaltic base petroleums to coal dispersions made from bituminous coals and topped tars it may be possible to produce hot-mix binders superior from the standpoint of temperature susceptibilities and brittleness at low temperature to those made with RT-12, coal, and high-boiling coal-tar oil.

It is unfortunate that time did not permit the performance of more extensive tests along these lines and it is hoped that they will be undertaken by other investigators.

Sand Blast Methods for Hot-Mix Binder Evaluations

During the course of the laboratory investigations at Quehanna, and field service tests in Kentucky, it became increasingly evident that better methods are needed for determining the temperature susceptibilities and particularly the brittleness at low temperatures of hot-mix binders. Of the various methods tried, it appears from one series of tests performed near the conclusion of the Quehanna investigations that most significant results might be obtained with a sand blast test developed in the laboratories of the Koppers Company. It was described by Rhodes and Gillander (26) at the 1936 HRB annual meeting.

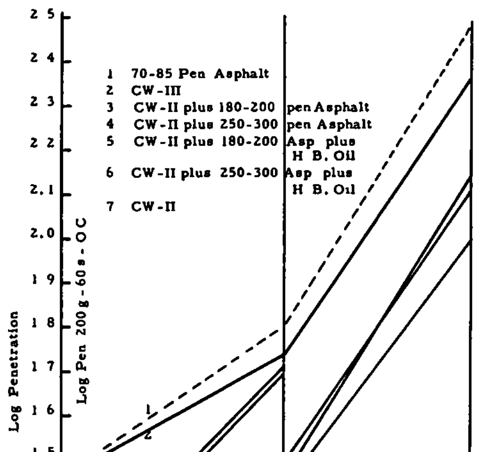


Figure 15. Temperature susceptibility curves for asphalt, CW-III, CW-II, and coal-modified CW-II plus soft residual asphalts with and without high-boiling coal-tar oil.

As applied to hot-mix binders in the Curtiss-Wright laboratories, the test was performed as follows: Ottawa sand was hot-mixed with 5 percent by volume of 70-85 asphalt, RT-12, topped RT-12, CW III, and CW II. For each mix, 25-g portions were compressed in 1-in. cylinders under 1,000-lb pressure. The compacted specimens cooled to 77 and 32 F were blasted with 25 g of Ottawa sand propelled by compressed air at 75- to 80-lb pressure. As in the original tests, the blasting was done with a modified spark plug cleaner.

The percent loss in weight for each sample was determined by weighing the specimens accurately before and after sand blasting. As given in Table 20 and the curves in Figure 16, significant differences in brittleness or abrasion resistance (as indicated by the different losses in weight) were determined for the various binders when tested by this method.

Especially significant was the fact that RT-12, which had the lowest abrasion loss

TABLE 19

CHARACTERISTICS OF ASPHALT, CW-III, CW-II AND CW-II MIXED WITH SOFT ASPHALTS WITH AND WITHOUT ADDED HIGH-BOILING COAL-TAR OIL

Binder	Soft. Pt (R & B)(°C)	Penetration 200-60-32 F	Penetration 100-5-77 F	Penetration 50-5-115 F	Suscept Factor	Penetration Ratio	Penetration Index
70-85 pen asphalt cement	49 8	28.3	63 0	303	4 4	4 0	-1 0
CW-III (79 RT-12, 7 2 coal, 13 8 h -b o)	48.2	28 3	55.0	230	3 5	4 0	-1 5
CW-II (90 RT-12, 10 coal)	55 0	9 6	28.5	139	--	--	-1 5
72 4 CW-II plus 27 6 asphalt							
180-200	56 8	28 0	31 0	130	3 3	4 2	-0 7
250-300	57.4	26 5	26 7	100	2 8	3.8	-1 0
68 CW-II + 27 asp. + 5 h -b.o.							
180-200	54 2	15 7	51 4	--[a]	--	--	0
250-300	53 5	15 0	49 7	--[a]	--	--	-0 3

[a] Too soft

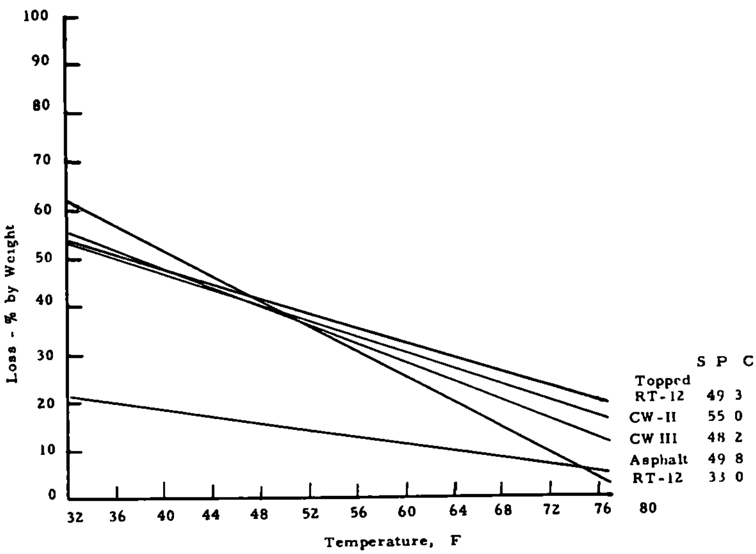


Figure 16. Abrasion losses from sand briquets containing asphalt, RT-12, topped RT-12, and coal-modified RT-12 binders with and without high-boiling oil (CW-III and CW-II).

TABLE 20

ABRASION LOSS AT 77 AND 32 F OF SAND BRIQUETS CONTAINING DIFFERENT BINDERS WHEN BLASTED WITH SAND

Binder	Soft. Pt. R & B (°C)	Wt. Loss at 77 F (%)	Wt. Loss at 32 F (%)
70-85 pen. asphalt cement	49.8	5.1	21.5
RT-12	33.0	3.0	62.2
Topped RT-12	49.3	19.5	53.5
CW-II (90 RT-12, 10 coal)	55.0	16.6	53.1
CW-III (79 RT-12, 7.2 coal, 13.8 h.-b. oil)	48.2	11.7	55.9

at 77 F (because of its comparatively low softening point), had the highest loss at 32 F indicating that it was the most brittle at that temperature. On the other hand, the asphalt specimen which had a weight loss almost as low as the RT-12 at 77 F had a much smaller loss (or brittleness) at 32 F showing that its temperature susceptibility in the range of 32 to 77 F was greatly superior to that of the RT-12. The Curtiss-Wright and topped RT-12 (pitch) binders had higher losses at 77 F than either the RT-12 or asphalt mixes but their losses (brittleness) at 32 F were intermediate between those of asphalt and RT-12. Applications of the sand blast test at 32, 77, and 115 F would appear to be a reliable way of comparing the temperature susceptibilities of hot-mix binders.

SUMMARY AND CONCLUSIONS

During the two-year period between December 1958 and December 1960 a Curtiss-Wright Research Division task force conducted laboratory studies at Quehanna, Pa., and pilot plant operations in Kentucky with a view to developing improved binders for bituminous concrete pavements by dispersing bituminous coal in coal tar, with or without the addition of oil, polymer, or asphalt modifiers.

Quehanna Investigations, 1959

During the first half of 1959, intensive investigations were conducted in the Quehanna laboratories with the following results:

1. Three bituminous coals from the Quehanna area were digested at 600 F in a topped coke-oven coal tar meeting standard specifications for road tar of the RT-12 grade. Although their proximate analyses were similar, one of the coals, at 4.8 percent concentration, raised the softening point of the mixture only 2 C, whereas the increase for each of the other coals was approximately 8 C. One of the latter, from the Lower Freeport seam, near Quehanna, was selected for use in the subsequent studies.
2. From a series of tests in which coal was heated to 600 F in RT-12 and also in high-boiling coal-tar oil under various operating conditions it was concluded that neither pressure nor reflux was required to disperse the coal effectively in either material. The high-boiling coal-tar oil, derived from high-temperature coke-oven tar, complied with the following specifications: not more than 5 percent distillate to 315 C and 70-75 percent distillation residue at 355 C.
3. A small increase in softening point (2.5) accompanied the mechanical mixing of coal with RT-12 but a much greater increase (17.8) occurred when the same mixture was digested at 600 F. As shown by microscopic examination the pulverized coal particles, which were clearly visible in the mechanical mixture at 400 magnification, had completely disappeared after digestion at 600 F.
4. Softening points were increased progressively when increasing amounts of coal were digested in RT-12 at 600 F but the temperature susceptibilities of the coal dispersions in the temperature range of 25 to 32 C, as indicated by log penetration-temperature curves, were alike and substantially the same as that of the original RT-12. Also, they were somewhat higher than that of a typical 70-85 penetration asphalt paving cement.
5. The removal of increasing amounts of distillate from RT-12 produced pitches with increased softening points and increased temperature susceptibilities. In other words, as their softening points increased with removal of increasing amounts of distillate, their temperature susceptibilities became greater (poorer) as compared with the original RT-12 or with a typical 70-85 penetration paving asphalt.
6. Three-component dispersions of coal in RT-12 and high-boiling coal-tar oil (CW-III) had better temperature susceptibilities than two-component dispersions containing only coal and RT-12 (CW-II). The temperature susceptibility of a dispersion containing 20 percent coal, 20 percent RT-12 and 60 percent high-boiling coal-tar oil was somewhat better than that of a typical 70-85 penetration asphalt. The temperature-susceptibility curve for the latter was most nearly duplicated by a CW-III dispersion containing 19 percent coal, 52.5 percent RT-12, and 28.5 percent oil.

7. Comparative laboratory tests on samples of 70-85 penetration asphalt; RT-12; a CW-II dispersion containing 10.8 percent coal and 89.2 percent RT-12; and a CW-III binder containing 11.4 percent coal, 64.4 percent RT-12, and 24.2 percent oil showed that the latter should compare most favorably with asphalt as a binder for bituminous concrete pavements. Its penetrations at 25 and 32 C most nearly coincided with those of the asphalt although its softening point was approximately 6 degrees lower. From distillation and loss-on-heating tests it appeared to be considerably better than either the RT-12 or CW-II but somewhat poorer than the asphalt cement. Aqueous stripping and jet fuel solubility tests indicated that the CW-III should be far superior to the 70-85 asphalt and at least equal to the CW-II and RT-12 with respect to adhesion to aggregates and insolubility in petroleum oils.

8. The four binders previously mentioned were mixed with a typical aggregate, Marshall briquets were made and they were subjected to various tests with the following results:

(a) Marshall stabilities with both of the CW mixes were about 50 percent higher than that of the asphalt mix and about 100 percent higher than the stability of the RT-12 mix.

(b) Flow numbers for the CW mixes were intermediate between those of the asphalt and RT-12 mixes.

(c) The CW mixes and asphalt mix were very similar with respect to unit weight, percent voids filled, and percent voids total mix.

(d) Impact tests were slightly better for the asphalt mix.

(e) The heating of asphalt and CW-III briquets at 140 F for 72 hr caused the latter to lose 0.6 percent as compared with a loss of 0.04 percent from the asphalt briquets.

(f) The 72-hr heating test caused the asphalt briquets to suffer a greater decrease in Marshall stability (20 percent) than the CW-III briquets (3 percent). It also caused a decrease in the impact resistance of the asphalt briquets at 32 F, whereas that of the CW-III briquets increased appreciably.

(g) Jet fuel solubility of asphalt briquets was approximately 20 times greater than that of CW-III briquets.

(h) Immersion in water for 96 hr at 120 F caused a 17 percent decrease in the Marshall stability of asphalt briquets, whereas briquets made with CW-III, CW-II, and RT-12 binders increased in stability by 88, 9, and 14 percent, respectively.

9. Miniature pavements were constructed with hot mixes containing the asphalt, RT-12, and CW-III binders discussed. They were used to demonstrate the superior jet fuel resistance, skid resistance, and resistance to shoving or rutting obtainable with hot-mix binders of the coal and oil-modified tar type (CW-III).

10. Public announcement of the Quehanna investigations was made on April 7, 1959, in Harrisburg, Pa. The results of the laboratory tests were reported and the demonstration models were exhibited in support of tentative conclusions, based on the laboratory investigations, that it should be possible to produce improved, coal-based binders for use in the construction of bituminous pavements of the hot-mix, hot-lay type.

Kentucky Pilot Plant and Experimental Pavements, 1959

In June 1959 the Curtiss-Wright Corporation contracted with the State of Kentucky to build and operate a pilot plant for the production and delivery of 150,000 gal of coal-based binder to the Kentucky Department of Highways for experimental purposes. Construction of the plant at the Central Garage of the Highway Department in Frankfort, Ky., was completed in August 1959.

The pilot plant consisted of a digester of 1,500-gal capacity, tank cars for the storage of RT-12, high-boiling coal-tar oil and finished binders, transfer pumps and pipelines, a pulverized coal loading conveyor, and a steam boiler.

The digester, which was specially designed for the purpose, consisted of a vertical tank, heated only on the sides with combustion gases from two oil burners. It was equipped with a high-speed agitator, an internal water coil for cooling the finished binder, a reflux condenser and receiving tank for distillates, and a bottom internally-seated valve through which the finished binder was transferred to tank car storage or transport trailers.

Operation of the digester was as follows: RT-12 grade road tar, pulverized Kentucky coal, and high-boiling coal-tar oil were transferred to the digester from storage in the proportions indicated by laboratory tests previously made at Quehanna. The mixture was heated as rapidly as possible to 600 F and maintained at that temperature without reflux for ½ hour. By means of the internal water cooling coil the temperature was reduced to 400 F and the finished binder was then transferred to storage or transports.

During the period between August 13 and November 7, 1959, 104 batches of hot-mix binder, totaling 152,000 gal, were made. One hundred batches were of the three-component type (CW-III) with the following average composition: 81 percent RT-12, 11.0 percent high-boiling coal-tar oil, 8 percent coal. Two batches were of the two-component type (CW-II) with an average composition of 96 percent RT-12 and 4 percent coal, and two batches consisted of RT-12 which required only heating to 400 F before delivery to test sites.

Only minor difficulties were encountered in the operation of the pilot plant and, with it, the feasibility of commercially producing coal-modified tar binders comparable in quality to those produced experimentally in the laboratory was established.

The coal-modified tar binders produced in the pilot plant were delivered by tank trucks to fourteen test sites in various parts of Kentucky, where they were mixed with aggregates in existing hot-mix plants. No major difficulties were encountered at any of the plants and, except for contamination of a few first batches of hot-mix with asphalt or diesel fuel, operations were normal in all respects.

At two of the test sites the CW-III binder was used in hot mix laid 2 ¾ in. thick on a tar-primed soil base. At all of the other test sites the binder was used in 1 ½-in. Class I overlays on existing black top pavements which, for the most part, had previously required a large amount of maintenance because of base failures or the development of slippery surfaces. At none of the test sites was any of the experimental hot mix used for the construction of new pavements of the binder and surface course types or as an overlay on portland cement concrete.

Using standard equipment and paving procedures, and with atmospheric temperatures ranging from 27 to about 100 F, the hot mixes containing coal-modified tar binders were laid without any major difficulties. A quick firming of the hot mix permitted rolling close to the pavers and enabled heavy traffic to pass over the newly laid pavements sooner than usual without damaging their surfaces or edges. Fuming of the mix was somewhat excessive, particularly at the start when the temperature of the mix at the paver was about 300 F, but with laying temperatures in the range of 200 to 260 F fuming was greatly reduced and no laying difficulties due to the lower temperatures were encountered.

The last test sections were laid near London, Ky. in November 1959 with atmospheric temperatures ranging from 28 to 37 F. At that time all of the test sections appeared to be in the same good condition as when originally laid. However, it was observed four months later that the coal-modified binder sections at London had raveled somewhat and had been abraded excessively by tire chains during the severe winter months due probably to insufficient compaction of the surfaces during their cold weather installation. Also, some cracking was observed on other test sections which became less noticeable during the following summer months due to self-healing, but inspections in October 1960 showed that several of the test sections were beginning to reflect movements and defects in the underlying bases indicating that they did not have sufficient flexibility to conform to such movements and irregularities without cracking. It appeared evident that the coal-modified tar binders should have had somewhat lower softening points and higher penetrations or that further modifications were needed to improve their temperature susceptibilities.

Quehanna Investigations, 1960

Soon after completion of the test sections in Kentucky, laboratory studies were resumed at Quehanna with a view to making further improvements in the manufacture and use of coal-modified tar binders. The results of those studies were as follows:

1. Absolute viscosity determinations at various temperatures showed that coal-modified tar binders of the types used in the test sections had appreciably lower viscosities than the asphalt cement used in Kentucky indicating that the coal dispersions should not need to be mixed or laid at temperatures as high as those required for asphalt cements. Mixing and laying temperatures in the range of 200 to 250 F should be adequate thereby minimizing the fuming which accompanies the use of higher temperatures.

2. Ten percent dispersions of coal in RT-12 were made with 26 samples of bituminous coal from Kentucky and with 23 samples from ten different locations in North America, South America, and Japan. Their softening points varied from 40 to 65 C but they all appeared to have approximately the same temperature susceptibilities in the range of 25 to 32 C.

For these tests 25-g portions of each coal were dispersed in 225 g of RT-12 by heating the mixture, with agitation and reflux of vapors, to 600 F for 1 hr. The results were comparable to those obtained from Quehanna autoclave and Kentucky pilot plant digestions.

3. Ten percent dispersions of Freeport seam coal were made in soft pitches produced by topping low-, medium-, and high-temperature coal tars from various sources. It appeared from softening point and penetration determinations that the coal was dispersed most completely in the pitch from high- and medium-temperature tars.

A soft pitch from Disco tar, which has many of the characteristics of medium temperature tars, produced a dispersion that had practically the same temperature susceptibility as 70-85 penetration asphalt, was better than the asphalt with respect to water stripping and jet fuel solubility, but not quite as good in the latter respect as dispersions made with high-temperature coke-oven tar (RT 12). Marshall briquets made with the Disco dispersion had high stabilities and other desirable characteristics.

4. Small amounts of various polymers were added to a three-component coal dispersion (CW-III) with a view to improving its low-temperature brittleness. Included in the tests were Hycar latex, natural rubber latex, reclaimed rubber, neoprene powder, neoprene latex, butyl rubber, Vistanex, and Thiokol LP-3.

On heating to 325 F for 5 hr all of the mixtures became non-uniform and/or crusted except those containing butyl rubber, Vistanex, and Thiokol. They remained uniform and had slightly reduced fuming tendencies; the Vistanex appeared to improve the CW-III somewhat with respect to temperature susceptibility. Further work with butyl rubber, Vistanex, and Thiokol appeared to be warranted.

5. Three different fluxing oils of petroleum origin were found to be unsatisfactory as substitutes for high-boiling coal-tar oils. They appeared to make homogenous mixtures when first added to coal dispersions of the two-component type (CW-II) but pronounced separations took place when the mixtures were subjected to the loss-on-heating test for 5 hr at 325 F.

6. By adding high penetration residuals (180-200 and 250-300) from asphaltic base petroleum to a coal dispersion containing coal and RT-12 (CW-II), binders were produced that appeared to be superior to asphalt and also to dispersions containing coal, RT-12, and high-boiling oil (CW-III) with respect to temperature susceptibilities in the range of 32 to 77 F. More extensive tests of this nature should be performed.

7. Recognizing the need for a better method of evaluating hot-mix binders with respect to temperature susceptibilities in general, and low-temperature brittleness in particular, a sand blast method first proposed by Rhodes and Gillander in 1936 (26) was tried. Ottawa sand was hot mixed with 5 percent by volume of 70-85 asphalt, RT-12, topped RT-12, CW-III, and CW-II. Then 25-g portions of each mix were compacted in 1-in. diameter cylinders under 1,000-lb pressure. The compacted specimens were cooled

to 77 F and 32 F and then blasted with 25 g of Ottawa sand. By weighing the specimens before and after sand blasting, their percentage losses in weight were calculated. Significant differences were determined for the different binders and further work with this method of test appears to be in order.

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

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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 (1/8 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 1/2-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

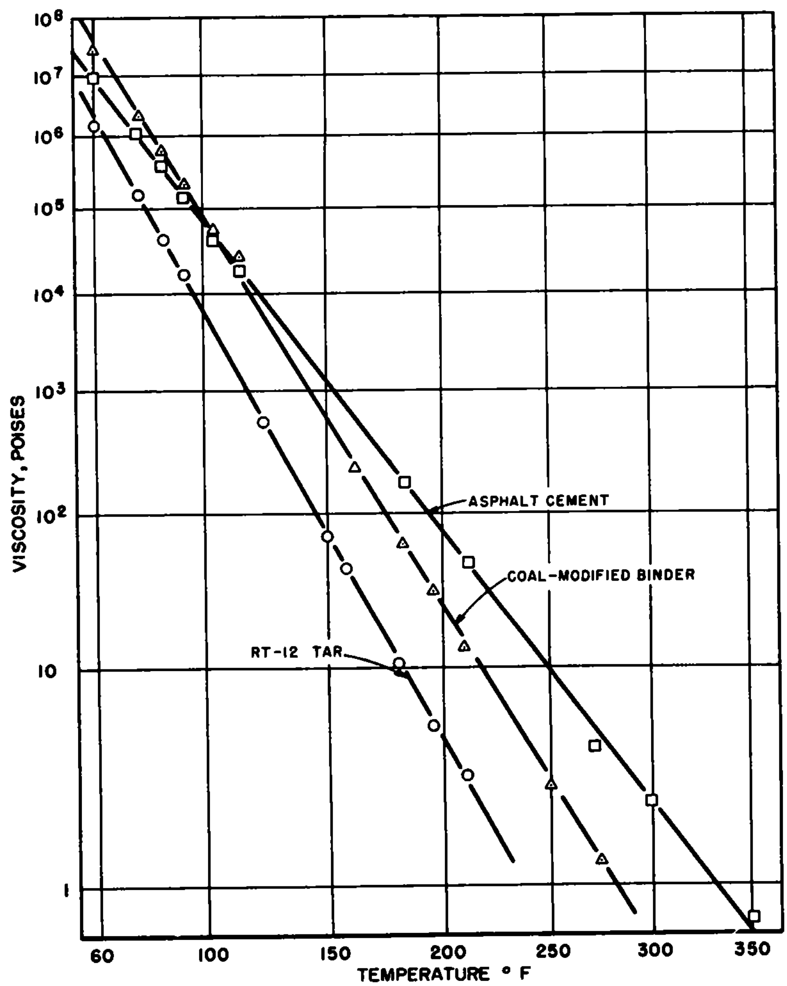

Figure 1. Viscosity-temperature relationships for binders used in Kentucky experimental projects.

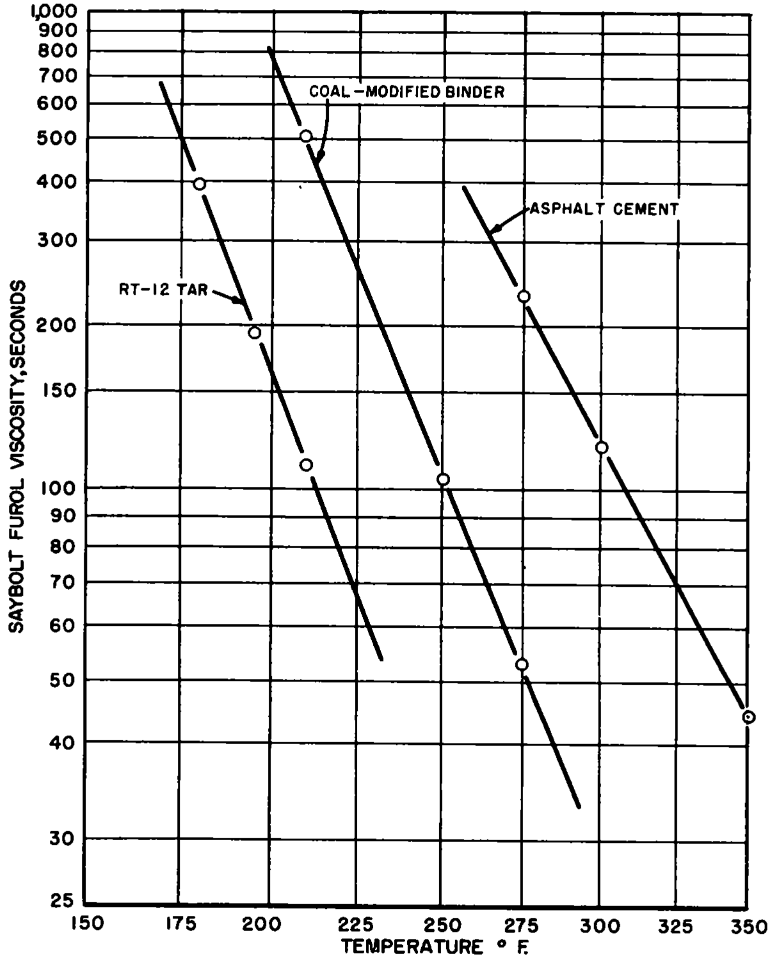

Figure 2. Furol viscosity of binders at various temperatures.

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 (1/8 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

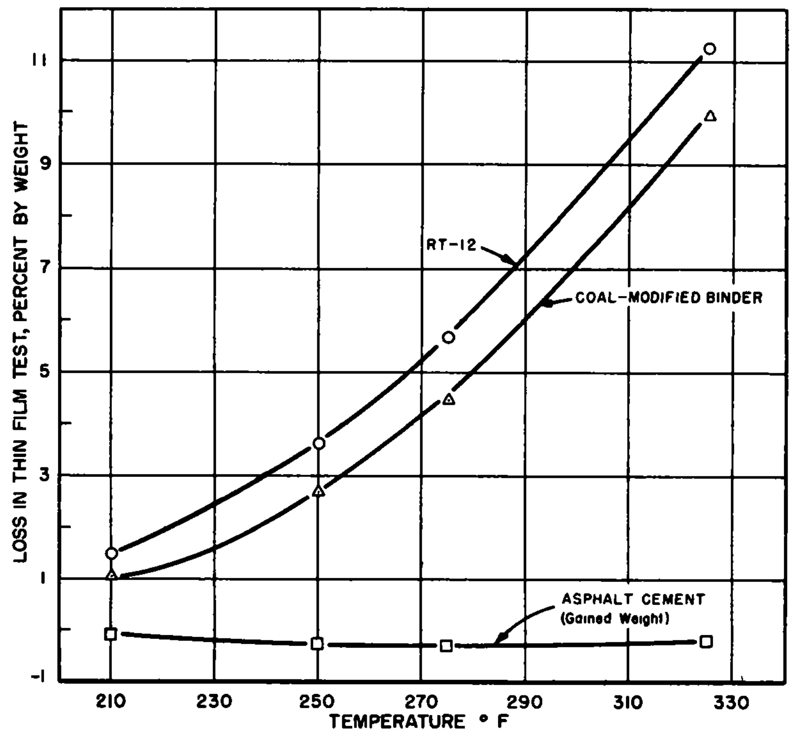

Figure 3. Weight loss in thin film test at various temperatures.

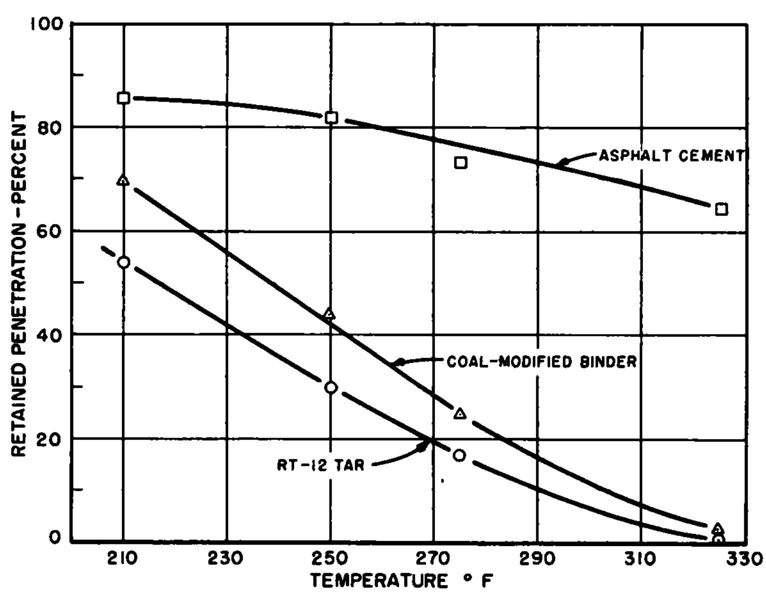

Figure 4. Resistance to hardening at various test temperatures (1/8-in. film, 5 hr).

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.

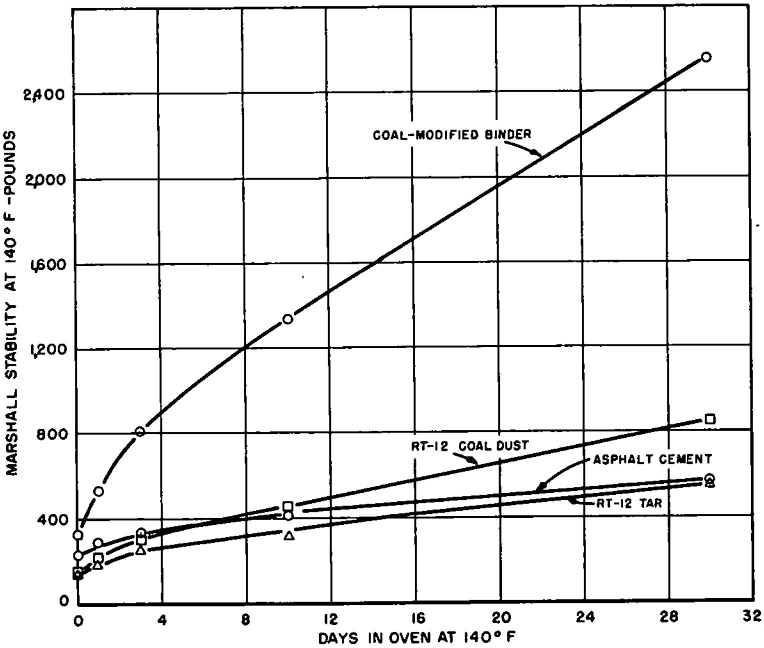

Figure 5. Increase in Marshall stability during time of aging in oven.

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.

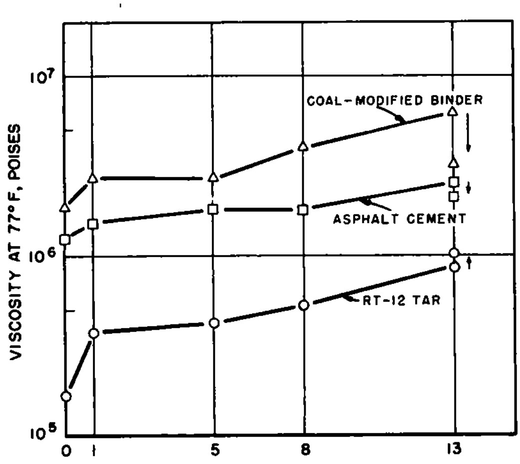

Figure 6. Effect of aging at 110 F on binder viscosity.

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

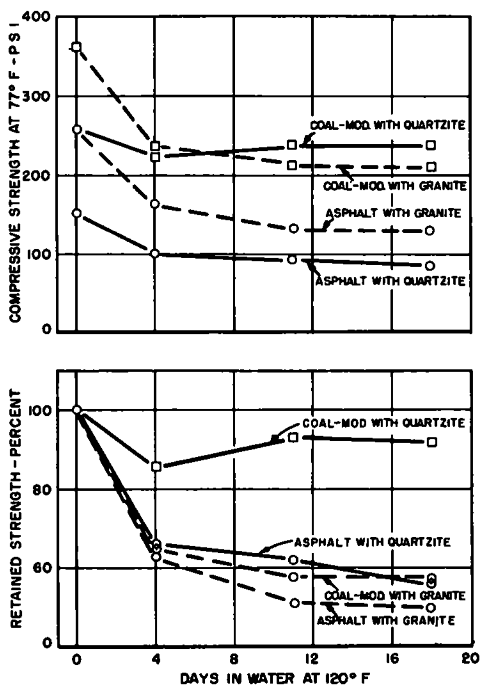

Figure 7. Effect of water immersion on stability.

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

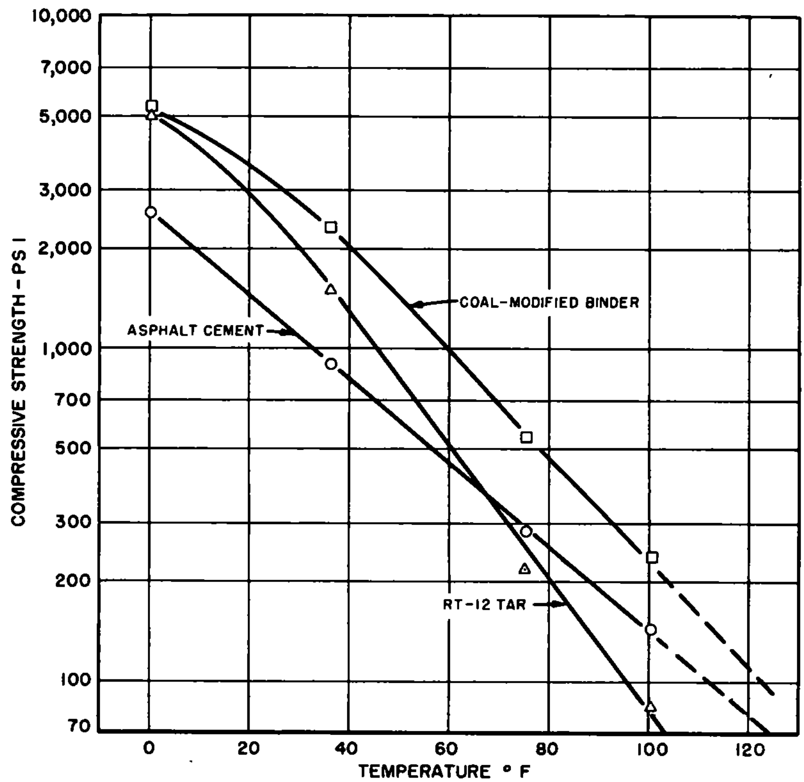

Figure 8. Variation of compressive strength with temperature.

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.

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Experimental Paving Projects Using Curtiss-Wright's Coal-Modified, Coal-Tar Binder

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This report covers the observation and evaluation of 13 sections of experimental pavement constructed in Kentucky using coal-modified, coal-tar binder. These are compared with the performance of control sections in which normal specification asphalt cements were used. The results of laboratory and field tests are also reported to support and supplement the visual surveys.

• EARLY in April 1959, the Curtiss-Wright Corporation announced the development of a new coal-based road-paving binder utilizing substantial quantities of bituminous coal. The basic principles used in preparing this bituminous binder was the digestion of powdered coal in coal tar and tar oils at temperatures of 500 to 600 F. By adjusting the proportions of tar, tar oils, and coal, binders could be prepared having penetration ranges comparable to asphalt cements. It was the intent of the developers that the modified binders be used in the same manner as asphalt cements in hot-plant mixtures.

Because of the significance that bituminous coal plays in the economy of Kentucky, State officials were interested in any potentialities that might utilize large quantities of coal. Kentucky officials met with Curtiss-Wright representatives regarding the possibility of producing the coal-based binder for Kentucky highways and of utilizing Kentucky coal. At that time, the development of the coal-based binder had not progressed beyond the laboratory phase. Most of the laboratory data had been obtained with an RT-12 grade of coke-oven tar, into which 5 to 10 percent of pulverized bituminous coal had been digested. The mixture was heated 500 to 600 F for approximately one hour under atmospheric refluxing, wherein the volatile oils were either retained in the mixture or else recovered and replaced by a less volatile tar oil to achieve the desired consistency of the finished product.

It was found, again on a laboratory scale, that the properties of the digested materials differed from those of currently available coal tar or from mechanical blends of coal and tar. Primarily, the Curtiss-Wright binder was less susceptible to consistency changes with temperature than RT-12 coal tar. It was also more resistant to hardening than the normal road tar when heated to the temperature usually used in mixing asphaltic concrete.

On June 22, 1959, the Department of Highways entered into an agreement with the Curtiss-Wright Corporation in which the latter would design, build, and operate a pilot plant to produce 3,000 gal per day of binder. The Department of Highways was to select sites, supervise construction of test sections of roads, and evaluate the performance of the sections.

The Corporation completed the pilot plant on August 17, 1959. It was located at the central garage of the Kentucky Department of Highways in Frankfort. The batch plant had a 1,500-gal capacity. Approximately 1,200 gal of RT-12, 300 gal of a high-boiling point coal tar oil, and 1,100 to 1,500 lb of coal (pulverized so that 90 percent would pass a No. 200 sieve) were processed in each batch. The last batch of the experimental binder was produced on November 4, 1959.

A total of 13 sections of pavement on 12 projects were selected and constructed throughout the State to evaluate the binder. These sections were constructed as part of normal asphaltic concrete paving contracts in which the coal-based binder was substituted in a length of each pavement. Included in the experimental sections were resurfacing of bituminous pavements and initial paving over traffic-bound granular bases. Some of the sections were in the light rural traffic class, and others were in a relatively heavy traffic class. The last of these sections was completed on November 7, 1959.

During the two years since construction of the test sections, the pavements have been under observation and study. Tests in the laboratory and field have been made to evaluate further the information recorded from the visual surveys. Movie films and still photographs were made before and after paving in order to record the two conditions. Additional photographs have been taken when performance conditions indicated the need.

This report covers the test site selection, construction of the test sections, and performance during the first two years of service.

SELECTION OF TEST SITES

It was decided by the Research and Construction Divisions of the Kentucky Department of Highways that because of the time involved and other factors, it would be necessary to arrange for change orders on existing bituminous concrete paving projects so as to complete the test installations during the pilot plant production period (August to November). Because the binder was an experimental material, the time limitation did not permit the selection of projects in which there was Federal participation.

The selection of test sites was limited to the following groups of projects: State project (SP), initial treatment (IT), rural secondary (RS), and rural highway (RH). The proposals on all bituminous hot-plant-mix paving projects under construction in these groups were studied and screened. Fifty roads that were to be paved in the construction season of 1959 were selected for visual study. The visual study included visiting each road, making notes on its condition, and taking photos of representative sections. The base and drainage conditions were especially noted; a road with a very poor base and/or totally inadequate drainage was eliminated from consideration.

As a result of numerous roads being eliminated for one or more of the reasons discussed, 20 possible test sites remained for consideration after the visual surveys were completed. Construction of test sections on different types of roads under a variety of traffic conditions was desired; therefore, the type of construction proposed on each road was tabulated from information received from the Construction Division and the latest traffic counts on each road still under consideration were listed from the files of the Planning Division. On these bases, 12 projects, including 13 Curtiss-Wright binder test sections, were selected for use in this experimental work.

Table 1 gives the approximate location, contractor, traffic data, and type of construction proposed for each project. The 13 test sections were located in 12 counties, and 9 different contractors were involved. Eleven 1 ½-in., Class I resurfacings and two 2 ¾-in., modified Class I base, initial-treatment pavements were included. The average traffic count ranged from 50 to 14,150 vpd.

After individual discussions explaining the over-all project with the contractors involved, a change order was prepared by the Construction Division for each project. In effect, these change orders provided that the Department furnish the contractor the experimental binder at no charge as compensation for the extra expense and time required for construction of the test section. The contractors agreed to this arrangement.

CONSTRUCTION

A control section of pavement containing asphaltic binder was constructed near or adjacent to each test section so that comparisons could be made between the conventional binder and the experimental Curtiss-Wright Binder. The roadways on which the control and test sections were paved were selected so as to have approximately

TABLE 1

PROJECTS SELECTED FOR EXPERIMENTAL PAVEMENT SECTIONS

Group No.[1]	County	Approx Location	Contractor	Location of Plant	Traffic (ADT)
S P Gr. 6	Allen	Ky 101 in Scottsville	McLellan Stone Co.	Scottsville	1,025 (57)
S.P. Gr. 11 urban	Laurel	US 25 in London	Cantrill Constr. Co., Inc.	London	14,150 (58)
S.P. Gr. 11 rural	Laurel	US 25 north of Lily	Cantrill Constr. Co, Inc	London	11,000 (59)
S.P Gr 16	Garrard	Ky 39 south of Lancaster	E'Town Paving Co, Inc	Mt. Vernon	1,070 (59)
S P Gr. 18	Magoffin	Ky 114 in Salyersville	Ky Road Oiling Co	Pomp (near West Liberty)	1,075 (59)
S.P Gr. 31	Nelson	US 31-E north of Bardstown	MaGo Construction Co, Inc	Bardstown	2,825 (58)
S P Gr. 32	Jackson	US 460 south of McKee	MaGo Construction Co, Inc	Near McKee	1,350 (59)
S P Gr. 37	Rowan	US 60 east of of Morehead	East Ky. Paving Corp	Olive Hill	2,407 (59)
S.P Gr 38	Perry	Ky 699 north of Leatherwood	Cantrill Constr Co, Inc	Leatherwood	1,125 (59)
S.P Gr. 45	Franklin	US 460 east of Frankfort	Robert L Carter Co	Frankfort	1,435 (59)
S P 54-140	Hopkins	Ky 70 east of Madisonville	Dixie Pavers, Inc	Henderson	2,660 (57)
I T Gr 14	Warren	Ky 185 south of Barren River	R. E. Gaddie, contractor	Bowling Green	50 (58)
I T. Gr 22	Rockcastle	Ky 618 east of Quail	E'Town Paving Co., Inc	Mt. Vernon	75 (58)

[1] All were 1 ½-in. Class I resurfacings except I. T. Gr 14 and 22 which were 2 3/4-in., modified Class I base, initial-treatment pavements.

the same base and drainage conditions. Thus, the only difference between a test section and its companion control section was in the binder. A sketch of the pavement structure for each test and control section is shown in Figure 1. Separate sketches are shown for the Allen County project because there was some variation in the construction history there. The elements shown in Figure 1 refer to prior applications of paving courses and their respective dates. Soundings were not made for this study. The test sections, of course, used the Curtiss-Wright Binder and the control sections were constructed with the asphaltic binders specified in the original project contracts. Both the experimental and the standard mixes were made and laid under the "Kentucky Standard Specifications for Road and Bridge Construction (1956)" which designates (a) the temperatures of the aggregates, binder, and mix at the plant and the mix at the paver; (b) the gradations of the aggregates and combined mixes; (c) mixing time; and (d) the type of asphaltic binder (for control sections only) and aggregate used. It was considered necessary to clean the plants and pavers before and after using the Curtiss-Wright binder. The plants were cleaned by pumping fuel oil through the lines while they were hot and by wasting the initial batch of material. A paver was cleaned by spraying it with fuel oil while it was still warm. Of course, precautions were taken to remove all the free fuel oil from the plant (weighing bucket, etc.) before any of the materials produced were used for paving.

The experimental binder was pumped from its storage tank (railroad tank car) at the Frankfort pilot plant into truck transports and hauled to each job. The trailers were 5,500-gal. insulated tankers equipped with propane heaters and temperature gages. One tanker was spotted at the hot-mix plant for storage. This trailer was hooked directly into each plant by running a line from the rear of the tank to the pump on the plant.

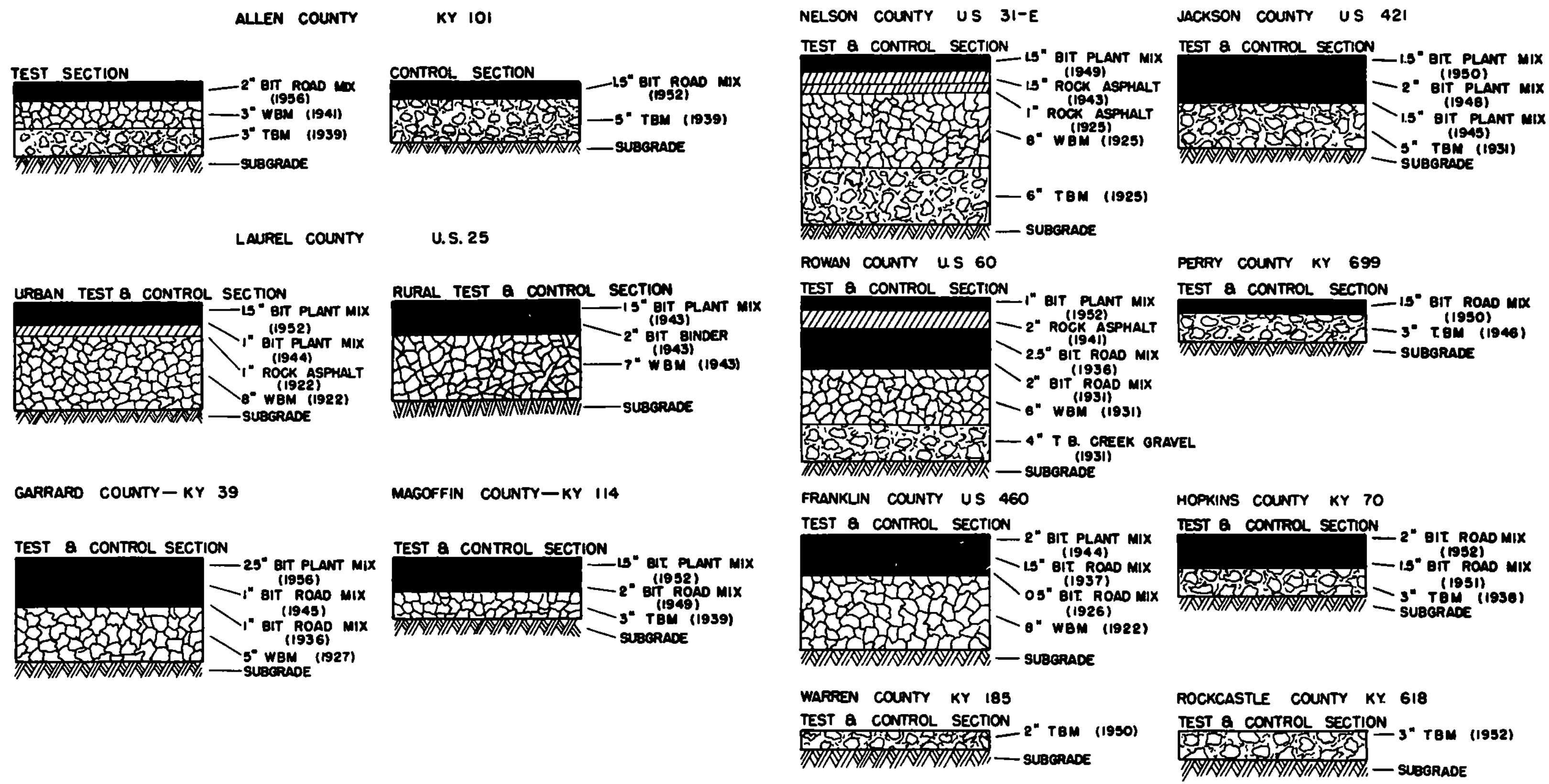

Figure 1. Experimental sections.

Samples were taken of the different types of aggregate, the asphaltic and experimental binder, and the final mixes used on each project. These samples were delivered to the laboratory for testing. The results from laboratory tests performed on the tar binders are given in Table 2. The RT-12 was the raw material used in the production of the Curtiss-Wright binder. It was supplied from materials obtained by Curtiss-Wright for the project. The asphaltic cement used in the control section for each project was tested for acceptance by the Department. The results of these tests are given in Table 3. One-half of the projects was designed for PAC-5 (85 to 100 pen.) and the other half for PAC-7 (120 to 150 pen.).

Average combined aggregate gradations for the test and control sections are given in Tables 4 and 5. Marshall test cylinders were prepared in the laboratory by reheating samples of the mixtures taken from selected projects. The test data on these specimens are given in Table 6. The average stability for the three component Curtiss-Wright binder surface mix was 1,696 lb and ranged between 846 and 3,059 lb. The flow for these samples averaged 7.9/100 in. Samples from four of the control sections of surface mix gave an average stability of 728 lb and flow of 8.1/100 in.

Hourly temperature records were made for (a) aggregate entering the hot mixing chamber, (b) Curtiss-Wright binder in storage at the plant, (c) mixture at the plant, and (d) mixture at the paver. The mix temperatures at the plant and at the paver have been given in Table 7 along with the type and capacity of the plant used on each project. To reduce objectionable fumes at the plants and pavers, operating temperatures were lowered somewhat below normal asphaltic mix temperatures on some projects. Specification ranges for asphaltic cements are 250 to 300 F for mix at plant and 225 to 275 F at paver. This change in operational temperature was made with the concurrence of the Curtiss-Wright project staff. Although lowering the mix temperatures at the plant lessened the amount of fuming, it did not eliminate the problem entirely.

TABLE 2

TEST RESULTS FOR TAR BINDERS

Binder	Project Number	County	Road	Sampling Date (1959)	Penetration at 25 C	Softening Point (°C)	Spec Gr at 25C/25 C	Solubility in CS_2 (%)	Thin Film Oven Test: Wt Loss (%)	Thin Film Oven Test: Penetr Residue at 25 C	Thin Film Oven Test: Soft Pt Residue (°C)
3-component	S P Gr 6	Allen	Ky 101	10-12	46 0	52 2	1 278	69 5	13 2	0	75 5
	S P Gr 11	Laurel	US 25[a]	11-4	54 5	52 2	1 272	71 8	13 1	0	74 1
	S P Gr 16	Garrard	Ky 39	9-24	52 0	50 0	1 294	71 2	15 2	0	82 2
	S. P Gr 18	Magoffin	Ky 114	9-18	67 3	47 8	1 253	74 1	15 2	0	77 7
	S P Gr 31	Nelson	US 31E	10-22	61 3	44 0	1 274	72 3	13 9	0	74 7
	S P Gr 32	Jackson	US 421	9-29	46 3	50 0	1 269	72 2	12 3	0	76 2
	S P Gr 37	Rowan	US 60	9-1	60 0	49 5	1 257	75 0	14 8	0	81 6
	S P Gr 38	Perry	Ky 699	10-6	39 0	51 0	1 278	70 1	11 0	0	73 0
	S P Gr 45	Franklin	US 460	9-8	48 3	56 1	1 257	70 1	13 6	0	78 2
	S P 54-140	Hopkins	Ky 70	10-15	68 0	45 0	1 225	73 2	13 7	0	70 0
	I T Gr 14	Warren	Ky 185	10-1	41 0	51 5	1 283	68 3	9 6	0	71 1
	I T Gr 22	Rockcastle	Ky 618	9-21	88 5	35 0	1 263	75 9	16 6	0	75 0
2-component	S P Gr 11	Laurel	US 25[b]	11-7	54 7	46 5	1 274	71 8	12 6	0	73 9
RT-12	S P Gr 11	Laurel	US 25[b]	11-7	205 0	---	1 284	77 9	16 5	0	73 0
	I T Gr 14	Warren	Ky 185	10-2	259 0	---	1 274	79 6	16 8	0	74 5

[a] Urban
[b] Rural

TABLE 3

ACCEPTANCE TEST RESULTS FOR ASPHALT CEMENTS

Project Number	County	Road	PAC Grade	Water Content	Spec Gr at 60 F/60 F	Solubility in CCl_4 (%)	Flash Point (° F)	Ductility	Penetration at 77 F	Loss on Heating: Wt Loss (%)	Loss on Heating: Penetr Residue (% of original)
S P Gr 6	Allen	Ky 101	7	0 0	1 035	99 9	600	100	130	0 14	91 1
S P Gr. 11	Laurel	US 25[a]	5	0 0	1 020	99 9	600	100	89	0 11	87 6
S P Gr 16	Garrard	Ky 39	5	0 0	1 035	99.9	600	100	92	0 13	89 0
S P Gr 18	Magoffin	Ky 114	7	0 0	1 016	99 9	600	100	126	0 12	90 9
S P Gr 31	Nelson	US 31E	7	0 0	1 032	99 9	600	100	138	0 12	90 9
S P Gr 32	Jackson	US 421	5	0 0	1 035	99 9	600	100	92	0 13	89 0
S P Gr 37	Rowan	US 60	5	0 0	1 018	100 0	600	100	95	0 12	87 0
S P Gr 38	Perry	Ky 699	7	0 0	1 017	99 9	600	100	132	0 10	86 1
S P Gr. 45	Franklin	US 460	5	0 0	1 023	99 9	600	100	88	0 14	91 1
S P 54-140	Hopkins	Ky 70	5	0 0	1 026	99 9	600	100	86	0 12	91 4
I T Gr 14	Warren	Ky 185	7	0 0	1 018	99 9	600	100	138	0 15	91 0
I. T Gr. 22	Rockcastle	Ky 618	7	0 0	1 034	99.9	600	100	130	0 14	88 2

[a] Urban and rural

TABLE 4

AVERAGE COMBINED GRADATIONS (Test Sections)

Section	Project Number	County	Road	Percent Passing Sieve 1½-In	1-In	¾-In	3/8 In	No 4	No 8	No 16	No 50	No 100	No 200
Surface	S P Gr 6	Allen	Ky 101			100 0	91 1	58 6	43 0	35 7	5 4	1 3	0 6
	S P Gr 11	Laurel	US 25[a]			100 0	92 9	60 6	37 9	24 6	3 4	0 9	0 4
			US 25[b]			100 0	94 0	60 3	42 1	24 5	3 7	1 7	0 9
	S P Gr 16	Garrard	KY 39			100 0	93 4	57 5	41 9	34 7	5 7	1 7	0 9
	S P Gr 18	Magoffin	Ky 114			100 0	94 2	60 1	39 3	33 4	7 6	1 8	0 7
	S. P Gr 31	Nelson	US 31E			100 0	91 8	58 2	42 0	34 0	5 8	3 1	1 9
	S. P Gr 32	Jackson	US 421			100 0	93 1	58 5	43 5	37 7	9 6	5 4	1 6
	S P Gr 37	Rowan	US 60			100 0	90 0	59 9	42 5	35 6	5 0	1 5	0 6
	S P Gr 38	Perry	Ky 699			100 0	92 3	57 1	41 6	33 3	5 5	1 4	0 4
	S P Gr 45	Franklin	US 460			100 0	96 4	61 7	41 0	35 8	11 1	1 7	0 6
	S P 54-110	Hopkins	Ky 70			100 0	92 0	65 4	48 8	36 9	7 4	1 5	0 8
Mod base	I T Gr 14	Warren	Ky 185	100 0	95 4	60 1		39 2	27 7	20 0	9 6	5 3	
	I T Gr 22	Rockcastle	Ky 618	100 0	88 1	59 9		37 7	27 8	18 2	4 6	1 7	

[a] Urban
[b] Rural

TABLE 5

AVERAGE COMBINED GRADATIONS (Control Sections)

Section	Project Number	County	Road	Percentage Passing Sieve 1½-In	1-In	¾-In	3/8 In	No 4	No 8	No 16	No 50	No 100	No 200
Surface	S. P Gr 6	Allen	Ky 101			100 0	90 6	58 9	42 3	34 7	4 2	1 2	0 7
	S. P Gr 11	Laurel	US 25[a]										
			Northern portion			100 0	87 9	56 1	40 7	35 6	4 1	0 8	0 4
			Southern portion			100 0	92 5	60 9	42 3	31 6	4 6	1 4	0 7
			US 25[b]			100 0	90 0	54 0	40 0	34 7	4 1	1 2	0 7
	S P Gr 16	Garrard	Ky 39			100 0	93 3	59 0	42 4	33 7	5 9	2 6	1 5
	S P Gr 18	Magoffin	Ky 114			100 0	92 5	62 7	41 2	30 9	4 5	1 0	0 3
	S P Gr 31	Nelson	US 31E			100 0	91 7	61 4	41 7	33 9	7 9	3 4	1 9
	S P Gr 32	Jackson	US 421			100 0	92 4	58 6	42 1	36 2	6 7	2 8	1 1
	S. P Gr 37	Rowan	US 60			100 0	92 9	54 5	42 6	31 8	4 9	1 9	1 1
	S P Gr 38	Perry	Ky 699			100 0	93 7	58 6	39 7	30 7	4 8	2 1	1 2
	S P Gr 45	Franklin	US 460			100 0	96 9	60 7	40 4	34 2	9 7	1 8	0 7
	S. P 54-140	Hopkins	Ky 70			100 0	--	67 2	47 2	--	21 6	4 2	--
Mod base	I. T Gr 14	Warren	Ky 185	100 0	93 3	59 4		39 2	31 3	23 1	10 5	5 2	
	I T Gr 22	Rockcastle	Ky 618	100 0	88 9	61. 1		37 8	28 2	20 7	7 4	2 8	

[a] Urban.
[b] Rural

TABLE 6

MARSHALL TEST RESULTS FOR SAMPLED MIXTURES (Reheated)

Section	Mixture	Project Number	County	Road	Sampling Date (1959)	Sampling Time	Bitumen Content	Stability (lb)	Flow (0 01 in)	Unit Wt (pcf)	% Air Voids
Surface	3-component				10-12	12 30 PM	6 9	1 765	8 2	133 2	14 3
	CW binder	S. P Gr 6	Allen	Ky 101	10-14	1 30 PM		1,061	6 3	133 7	14 3
		S. P Gr 11	Laurel	US 25[a]	11-4	10 15 AM	6 9	1,052	7 6	137 3	12 0
					11-6	11 30 AM	6 9	910	6 7	137 1	12 1
				US 25[b]	11-6	2 15 PM	6 9	846	5 6	136 0	12 8
					11-7	10 15 AM	6 9	1,062	7 5	135 3	13 3
		S P Gr 16	Garrard	Ky 39	9-24	11 30 AM	6 9	1 076	7 7	136 6	12 5
					9-25	1 00 PM	6 9	1,649	6 6	135 5	12 9
		S. P Gr 18	Magoffin	Ky 114	9-18	9 30 AM	6 9	2,747	4 5	137 8	11 4
						5 30 PM	6 9	3 059	9 3	141 3	9 6
		S. P Gr 31	Nelson	US 31E	10-22	11 15 AM	6 9	1 636	10 2	138 6	11 1
						4 15 PM	6 9	1 548	6 0	134 0	14 0
		S P Gr 32	Jackson	US 421	9-29	9 15 AM	6 9	4,645	12 3	137 5	11 8
						1 00 PM	6 9	3,501	4 5	--	20 0
		S. P Gr 37	Rowan	US 60	9-1	4 45 PM	7 0	1 463	6 9	137 2	12 1
					9-2	10 30 AM	7 0	1 615	10 3	140 9	9 8
		S P Gr 38	Perry	Ky 699	10-6	10 45 AM	6 9	1,046	10 6	129 0	18 1
		S. P Gr 45	Franklin	US 460	9-9	9 00 AM	6 9	1 426	7 0	138 0	11 9
		S P 54-140	Hopkins	Ky 70	10-15	11 00 AM	6 9	1,030	6 2	137 6	11 8
					10-16	12 30 PM	6 9	1,153	9 0	133 3	14 6
		Avg						1,696	7 9	136 5	12 9
	2-component CW binder	S P Gr 11	Laurel	US 25[b]	11-7	3 15 PM	6 9	740	4 3	138 6	11 1
	Asphalt cement[1]	S P Gr 18	Magoffin	Ky 114	9-18	5 30 PM	5 5	964	7 7	137 3	10 5
		S. P Gr 32	Jackson	US 421	9-28	6 30 PM	5 5	739	11 3	137 8	11 6
		S P Gr 38	Perry	Ky 699	10-7	1 00 PM	5 5	619	5 9	135 2	12 2
		S. P Gr 45	Franklin	US 460	9-8	11 30 AM	5 5	591	7 5	139 9	10 2
		Avg						728	8 1	137 5	11 1
	RT-12	S. P Gr 11	Laurel	US 25[b]	11-7	1 10 PM	6 9	348	5 5	141 7	8 9
Mod. base	3-component				10-1	2 30 PM	6 9	1,898	10 8	139 7	10 5
	CW binder	I. T Gr 14	Warren	Ky 185	10-2	9 30 AM	6 9	1,579	12 0	134 1	14 1
		I. T Gr 22	Rockcastle	Ky 618	9-21	12 45 PM	6 9	1,040	7 8	137 4	12 0
						4 30 PM	6 9	1,463	16 0	131 5	15 7
		Avg						1,468	11 6	135 6	13 1
	Asphalt cement[1]	I. T Gr 22	Rockcastle	Ky 618	9-21	6 00 PM	5 5	993	10 0	134 5	13 1
	RT-12	I. T Gr 14	Warren	KY 185	10-2	10 45 AM	6 9	1,501	7 5	141 5	9 3

[a] Urban.
[b] Rural

TABLE 7

CURTISS-WRIGHT BINDER MIXTURE

Project	County	Plant		Temperature (° F)	
		Type	Capacity	Plant	Paver
SP Gr 6	Allen	Cont.	83 T/hr	255-285	235-280
SP Gr 11[a]	Laurel	Batch	5,000 lb	240-270	230-265
SP Gr 11[b]	Laurel	Batch	5,000 lb	220-290	220-280
SP Gr 16	Garrard	Cont.	120 T/hr	240-280	230-270
SP Gr 18	Magoffin	Cont.	120 T/hr	240-265	220-245
SP Gr 31	Nelson	Batch	4,000 lb	255-275	240-260
SP Gr 32	Jackson	Cont.	150 T/hr	230-250	230-245
SP Gr 37	Rowan	Batch	6,000 lb	230-280	205-265
SP Gr 38	Perry	Cont.	150 T/hr	240-280	235-270
SP Gr 45	Franklin	Batch	4,000 lb	235-265	235-265
SP 54-140	Hopkins	Batch	3,800 lb	270-300	210-270
IT Gr 14	Warren	Batch	3,750 lb	250-265	220-260
IT Gr 22	Rockcastle	Cont.	120 T/hr	250-270	235-265

[a] Urban.
[b] Rural.

A summary of the construction data on the experimental sections is given in Table 8. Some 10.2 miles of pavement containing 150,900 gal of Curtiss-Wright Binder and 4,700 gal of RT-12 were placed in 13 test sections.

One hundred feet of movie film was taken on both the control and the test section before and after paving. This was done by mounting a photographer on top of a car

TABLE 8

CONSTRUCTION DATA—CURTISS-WRIGHT BINDER TEST SECTION

Project	Length (mi)	Mix (tons)	CW Binder (gal)	Aggregate Type and Size	Prime or Tack		Date(s) Constructed (1959)
					Type	Appl. (gal/sq yd)	
				No. 9 Ls.			
SP Gr. 6	0 5	920.39	13,500	Nat. sand	RS-1	0.05	Oct. 12, 13, 14
				No. 9 Ls.			
SP Gr.11[a]	0.5	831.80	13,000	Nat. sand	RS-1	0.05	Nov. 4, 6
			10,600	No. 9 Ls.			
SP Gr. 11[b]	0.9	947.23	(3,000-2 comp)	Nat sand	RS-1	0.05	Nov. 6, 7
SP Gr. 16	0.9	944.35	12,000	Nat. sand	RS-1	0 05	Sept. 24, 25
SP Gr. 18	0.8	665.01	9,500	Nat. sand	RS-1	0.05	Sept. 18
SP Gr. 31	1.0	1,017.38	14,300	Nat. sand	RS-1	0.05	Oct. 21, 22
SP Gr. 32	1.0	1,026.78	13,500	Nat. sand	RS-1	0.05	Sept. 29
SP Gr. 37	0.9	802.00	11,500	Nat. sand	RS-1	0 05	Sept. 1
SP Gr 38	1.1	995.87	13,500	Nat. sand	RS-1	0.05	Oct. 6, 7
SP Gr. 45	0.6	626.15	9,000	Nat. sand	RS-1	0.05	Sept. 9
				40% No. 9 Ls.,			
SP 54-140	1.0	916.31	13,500	10% No. 11 Ls.,	RS-1	0.05	Oct. 15, 16
				25% Nat. sand,			
				25% Ls. sand,			
				No. 6 Ls.	RT-2		
IT Gr. 14	0.5	658.59	8,000	Ls. sand	prime	0.04	Oct. 1, 2
				No. 6 Ls.	RT-2		
IT Gr. 22	0.5	677.45	9,000	Ls. sand	prime	0.04	Sept. 21
Total	10.2	11,029.31	150,900				

[a] Urban.
[b] Rural.

and traveling over the sections at 30 mph. Specially marked traffic cones were set along the edge of the roadway at 500-ft intervals so that different features of the surface could be located and referenced. The purpose of the initial film was to record the condition of the road before paving and to aid in the evaluation of the future surveys. The second set of films was taken to record the surface condition just after paving. Still photographs were made of irregular places in both the test and the control sections before and after paving. These photos were used for close study of specific conditions. The boundaries of the test and control sections were marked by 18- by 24-in metal signs. Each sign identifies an experimental or standard section and its length in miles.

The following items were observed during construction:

1. The Curtiss-Wright binder coated the aggregate exceptionally well.
2. Traffic could be permitted on a pavement that has been paved with the binder very early without apparent damage.
3. Fumes given off by the binder hot-mix created a difficult working condition for the construction personnel.
4. The binder mix "set" very quickly and was difficult to finish after initial compaction.
5. A tar-type tack coat would probably have been more compatible with the experimental binder than the emulsified asphalt tack used.

PERFORMANCE

Visual Surveys

During the two years since construction of the test sections, the Research Division of the Kentucky Department of Highways has been continuously evaluating this binder. Tests in the laboratory and field have been run to support the information gained from visual surveys. Still photos were made at approximately six-month intervals and more often if the performance indicated the need. The most reliable and usable information, that was collected on the project, was the visual performance surveys. These surveys were made monthly for the first year and semi-annually for the second, and as mentioned, included photographs of items noted in the surveys. Strip-type performance maps were prepared for each test section and its companion control section. The legend for the performance surveys is given in Figure 2, and typical performance maps are shown in Figures 3 and 4.

Six of the test sections are discussed to summarize the comparative performance of the test and control sections. One of the test sections (SP Group 31 in Nelson County) was resurfaced with an asphaltic emulsion seal coat late in 1961. Several of the test and control sections have required maintenance patching of one form or another.

SP Group 31 on US 31E in Nelson County is a primary highway and is second to SP Group 11, Laurel County, in average daily traffic volume. The structural pavement design is comparable to existing primary pavements and thicker than the secondary projects in this study (1). There was some cracking and raveling of the pavement before placing the test pavement and the control. Figure 5 was taken before paving the test section near station 370. The test pavement in this area showed considerable reflection cracking following the first winter season. Figure 6 shows the same general areas

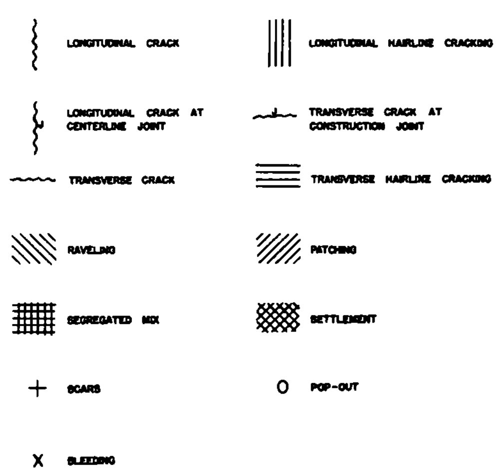

Figure 2. Legend for performance surveys.

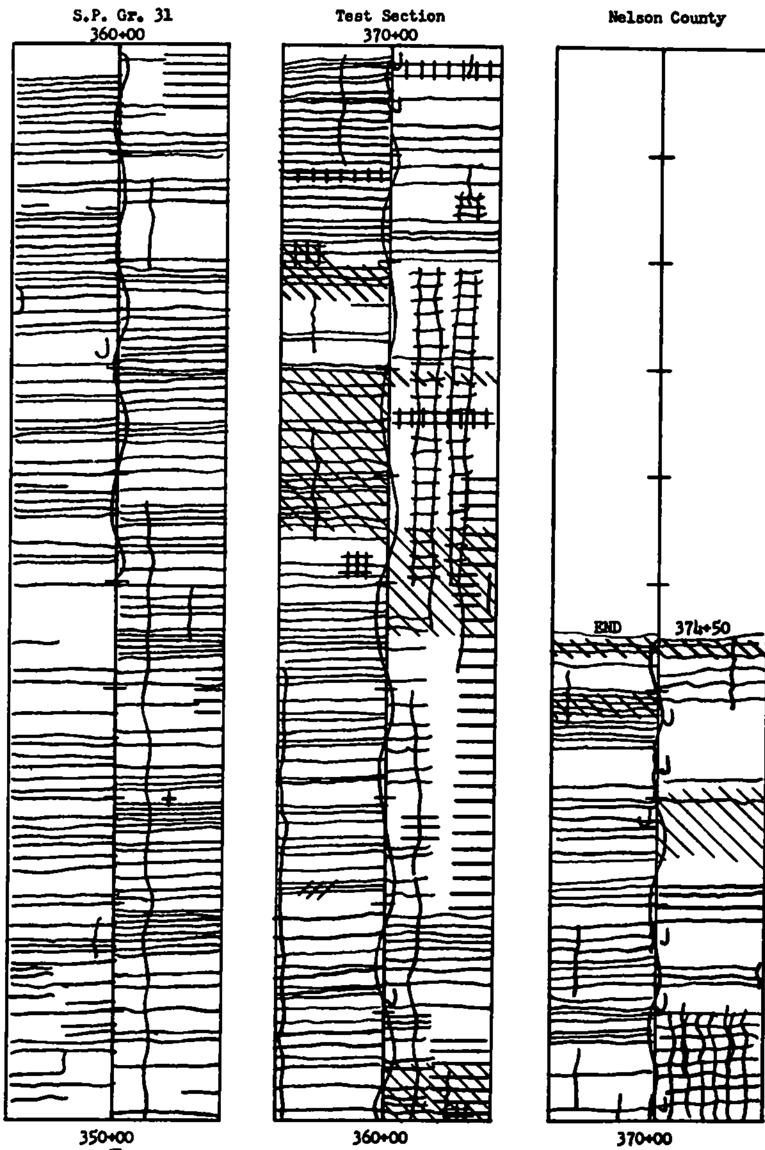

Figure 3. Performance-type strip map for approximately one-half of Nelson County SP Group 31 test section (2 years after surfacing).

as Figure 5 one year after paving. Figure 3 is the strip-type performance chart for part of the Nelson County project. This test section had deteriorated to such an extent that the Maintenance Division advised that the entire Curtiss-Wright binder-surfaced test section be covered with a seal-type application. An asphaltic emulsion seal was placed in the late fall of 1961 on this test section, as shown in Fig. 7. The control section for SP Group 31 (Figures 4 and 8) has evidenced minor surface failures and is performing very satisfactorily after two years.

The performance reports on the two test sections in Laurel County (SP Group 11) indicated that excessive raveling and wearing away of the surface was occurring as early as January 1960, or about three months after placement. These two sections on US 25 carried in excess of 11,000 vpd. The wear was progressive, and patching

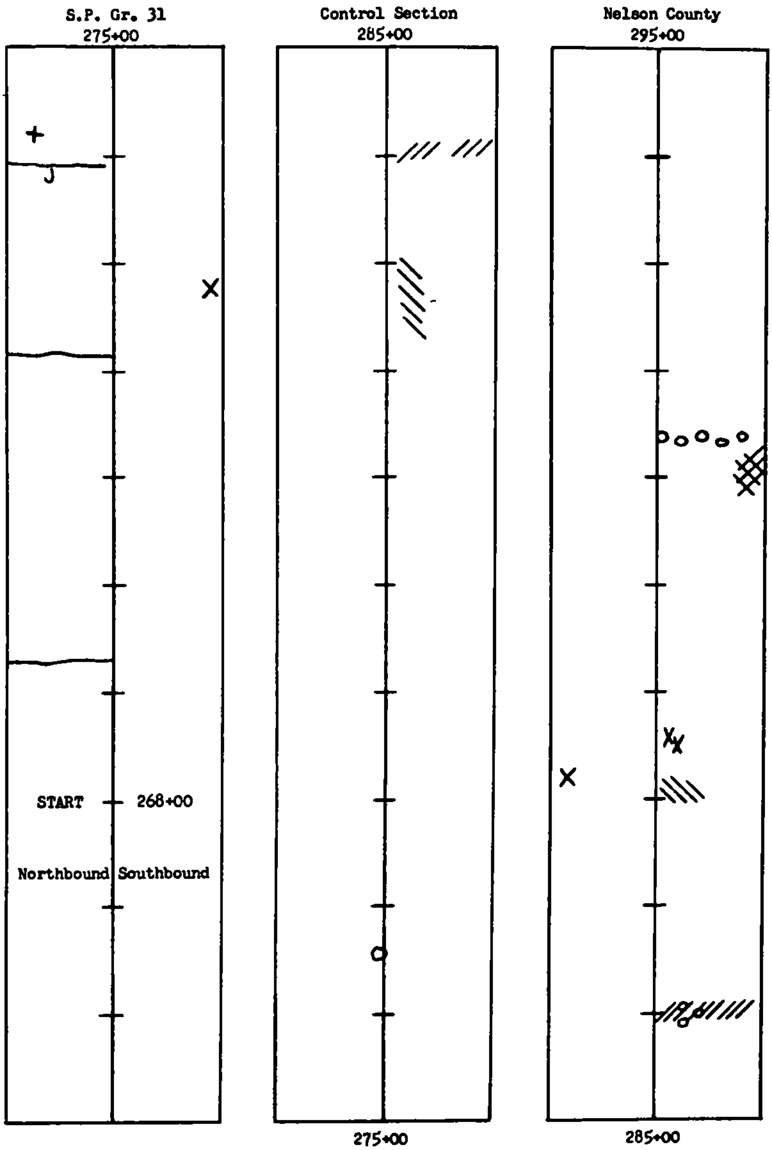

Figure 4. Performance-type strip map for approximately one-half of Nelson County SP Group 31 control section (2 years after surfacing).

was required in early spring. At several places in the urban sections, the entire thickness of the Curtiss-Wright binder surface was worn through. Some of the damage was accelerated through the use of tire chains; and, of course, the same vehicles operated on the urban control section with very little damage to the pavement. Figure 9 was taken approximately 6 months after paving and shows several places in the wheelpaths where the experimental pavement had worn through to the previous surface.

The control sections for both the urban and the rural parts of SP Group 11 are performing adequately and have required a minimum of surface maintenance.

SP Group 16, in Garrard County, gave some pronounced differences in the tests and control sections during the first winter of service. Figure 10 shows the very rough texture caused by erroding of the fine aggregate from the surface. Some tem-

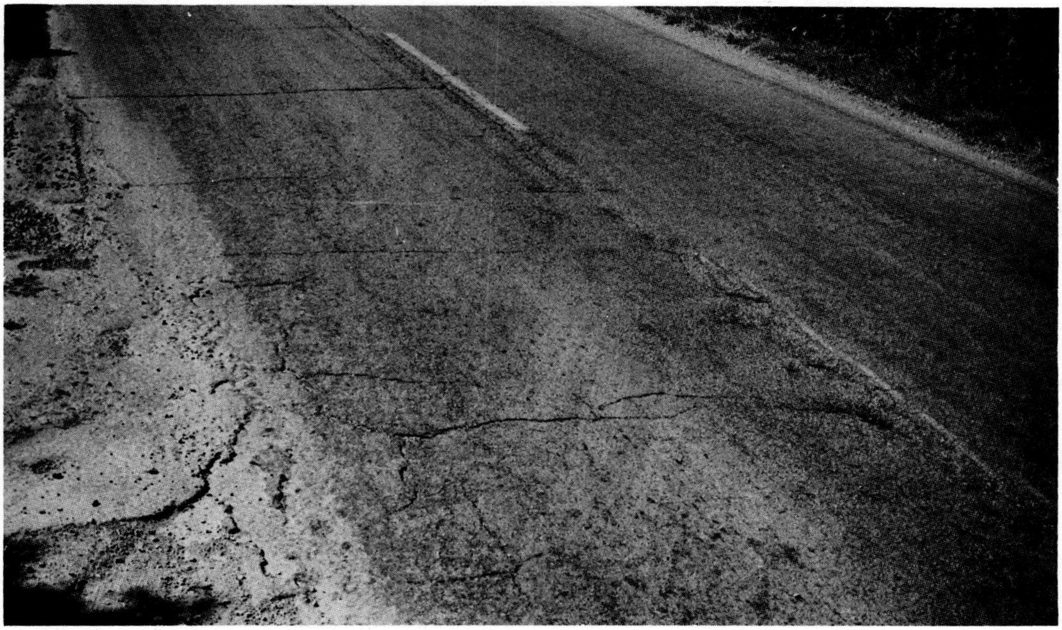

Figure 5. Area of transverse cracking near station 370 of Nelson County SP Group 31 test section (before surfacing with Curtiss-Wright binder).

Figure 6. Transverse cracks reflecting through Curtiss-Wright binder mix near station 370 of Nelson County SP Group 31 (one year after surfacing).

Figure 7. Nelson County SP Group 31 test section after an asphaltic emulsion seal coat had been placed (October 1961).

Figure 8. Nelson County SP Group 31 control section (October 1961). No surface maintenance required to date.

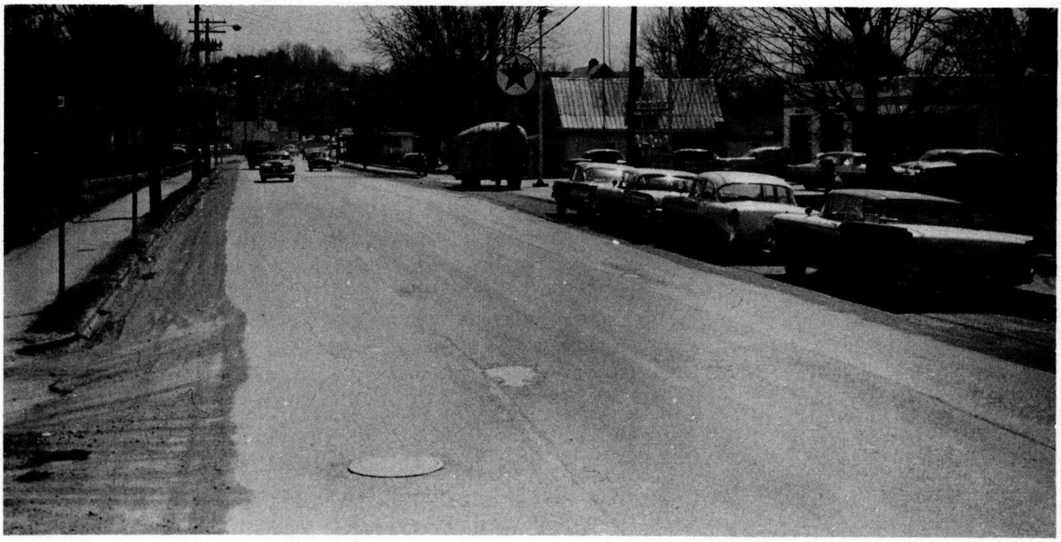

Figure 9. Raveled area near middle of SP Group 11, Laurel County urban test section (6 months after paving).

Figure 10. Garrard County SP Group 16 test section (October 1961). Note rough, open texture and pronounced center joint.

perature and reflection cracking can be seen. There is a difference in tire "hum" when driving over the open-textured Curtiss-Wright binder test section and the control section. The control section for this project is in excellent condition after two years.

SP Group 54-140, Hopkins County, has shown a considerable amount of cracking in the wheelpaths of the test section. There have been some surface failures in the control section, but they have been of a lesser extent.

There has been practically no surface defects appearing in either the test or control section of IT Group 22 in Rockcastle County. The traffic count is very low on this project (Table 1)—75 vpd. It may be some time before surface defects there require attention.

In discussing the five projects with six test sections separately, the total range of traffic volume and road classification has been included. It appears to date that the lower traffic volume roads (under 100 vpd) have not had sufficient traffic to show any appreciable difference in performance of the test and control sections. The medium (1, 000 to 2, 500 vpd) and the high traffic volume projects (2, 500 vpd and up) have experienced sufficient traffic to show some differences in the test and control sections.

Skid-Resistance and Roughness

The initial friction and roughness tests were performed in November 1959 which was soon after construction and before weathering and traffic could have had any significant influence on the surface characteristics of the pavements. Subsequent tests in May and October 1960 were intentionally scheduled so as to reflect any changes at the end of a winter and a summer season. The tests were conducted without any particular regard to temperature or weather; of course, tests were not made during freezing weather. An attempt was made to maintain the inherent and uniformity characteristics of the test methods throughout the test period.

Some of the roadways were characterized by curves, steep grades, and high crowns; these conditions interfered with the measurements. Two sections, IT Groups 14 and 22, were not evaluated with the roughness equipment. The urban section of SP Group 11 was eliminated because of inability to operate the equipment at test speeds.

Skewed-Wheel Method

The Kentucky Highway Materials Research Laboratory's skewed-wheel test (2) was used to measure the side friction between the pavement and the front tires of the test vehicle. This was the only test method that was used throughout all of the periods of skid-resistance testing. These data, as well as frictional values obtained by other methods of testing, were averaged for the respective types of surfaces. In considering the wet-friction coefficients, the over-all values for the control sections and the 3-component Curtiss-Wright binder sections were equal in November, 1959; whereas in May 1960 the coefficients on all sections had reduced slightly, but more so on the Curtiss-Wright binder sections. This trend was also apparent in October 1960.

By assigning a plus, minus, or zero to each of the projects to indicate whether the Curtiss-Wright binder section had the higher, lower, or equal coefficients as compared to the control sections, the wet, skewed-wheel test rated the 13 sections, as given in Table 9. Thus, 20 percent of the Curtiss-Wright binder sections had coefficients of friction that were higher than the control sections, 70 percent were lower, and 10 percent were approximately equal.

Concurrently with the wet-friction testing, skewed-wheel measurements were also made on the dry pavements. Dry-friction values, of course, tend to be higher and more uniform than wet-friction values, and they were used more as a calibration reference than as a criterion of skid-resistance. However, at the end of one year, the dry-friction coefficients for the control sections were slightly lower than those for the test sections.

TABLE 9

SKEWED-WHEEL TEST RESULTS

Date	No. of Coefficients		
	Plus	Minus	Zero
Nov. 1959	4	7	2
May 1960	2	9	2
Oct. 1960	2	11	0
Total	8	27	4
Percent of total	20	70	10

NCSA Bicycle Wheel Method

The National Crushed Stone Association friction wheel (3) was not used in the initial tests but was used in subsequent tests to supplement the skewed-wheel method. Approximately 2,000 individual tests were made during the 6-month and 1-year test series. By this method, the "skid" was about 5° higher on the Curtiss-Wright binder than on the control sections; this was so in both the 6-month and 1-year series of tests. However, even though this margin of difference persisted, the actual "skid" values increased between the 6-month and 1-year tests. The over-all increase was in the order of 3° for both the control and Curtiss-Wright binder sections.

Comparisons of the projects by the NCSA friction wheel, in the same manner described for the skewed-wheel test results, are given in Table 10. Only two of the Curtiss-Wright binder sections tested in May and one in October (12 percent of the projects) indicated a "skid" value lower than the control sections.

In computing the average values for the NCSA wheel, only the outer and inner wheel tracks were considered. However, generally the inner wheel track proved to be the slickest portion of the pavement, and the areas between the wheel tracks proved to be the most "skid" resistant. There was also a decrease in the apparent friction values for both the wheel tracks and the areas between them during the period from May to October 1960.

Skid-Resistance: Summary

By assigning equal importance to both the methods of test and by combining the results therefrom for each test period, a summary evaluation of the test binder sections, as compared to the control sections, was derived (Table 11).

Although the summary evaluation shows rather conclusively that the Curtiss-Wright sections have a tendency to become more slippery than the control sections, the actual

TABLE 10

NCSA FRICTION WHEEL TEST RESULTS

Date	No. of Coefficients		
	Plus	Minus	Zero
May 1960	2	11	0
Oct. 1960	1	12	0
Total	3	23	0
Percent of total	12	88	0

TABLE 11

SUMMARY OF TEST BINDER SECTIONS

Test	Date	Coefficients					
		Plus		Minus		Zero	
		No	%	No	%	No	%
Skewed wheel	Nov. 1959	4	30	7	54	2	16
Combined results	May 1960	5	19	20	77	1	4
	Nov 1959, May and Oct. 1960	12	18	50	77	3	5

TABLE 12

SUMMARY OF FRICTION TEST DATA

Pavement Section	Skewed Wheel Test[1]						Friction Wheel Test (°)[2]							
	Dry			Wet			Outside Wheel Track		Between Wheel Track		Inside Wheel Track		Wheel Track Average	
	Nov. 1959	May 1960	Oct. 1960	Nov. 1959	May 1960	Oct. 1960	May 1960	Oct. 1960	May 1960	Oct. 1960	May 1960	Oct. 1960	May 1960	Oct. 1960
Control	0.81	0.80	0.77	0 78	0.72	0 68	67	69	61	63	67	71	67	70
CW test	0.81	0 80	0.78	0 78	0.71	0.64	72	73	63	64	73	77	72	75
2-comp.	0.82	0.76	0 78	0.75	0.71	0.57	78	75	55	68	81	73	80	74
RT-12	0 83	0.76	0.78	0 79	0 68	0 68	74	76	66	62	68	66	69	71

[1] Average of 6,000 readings.
[2] 2,000 tests.

magnitudes of the differences in coefficients of friction, as derived from the several tests, were rather small (see Table 12).

Pavement Roughness Evaluation

A roughness test (4)—was performed on all of the projects on which it was possible to drive the test vehicle at 51.5 mph. The results from each test are given in the form of roughness index number which may be regarded as scalar values of roughness. Thus, an increase in the roughness index for each section during the total test interval is sufficient to describe the deterioration of the section of pavement. Using this as a basis for comparatively evaluating the performance of the control sections and the test sections, and as so given in Table 13, the Curtiss-Wright binder sections suffered the larger percentage of deterioration during the 2-year period.

Six out of the ten projects evaluated for pavement roughness showed a greater percentage deterioration for the Curtiss-Wright binder test section than the accompanying control section. Two of the control sections showed deterioration (percentage

TABLE 13

SUMMARY OF ROAD ROUGHNESS TEST DATA

Location	Traffic (ADT)	Binder	Roughness Index				
			Nov. 1959	May 1960	Oct. 1960	Dec. 1961	% Change
SP Gr 6	625	PAC-7	532	609	726	697	14
	1,025	CW	--	680	882	818	20
SP Gr 11[a]	14,150	PAC-5					
		CW	--	--	--	--	--
SP Gr 11[b]	11,000	PAC-5	436	460	485	536	23
		CW	347	511	570	616	77
		RT-12	390	485	553	565	45
		2-comp.	569	527	539	600	5
SP Gr 16	1,300	PAC-5	666	630	751	810	22
	1,070	CW	575	634	680	764	33
SP Gr 18	1,075	PAC-7	--	507	610	497	0
		CW	--	450	575	455	0
SP Gr 31	2,825	PAC-7	483	497	498	--	3
		CW	482	527	547	--	13
SP Gr 32	1,350	PAC-5	609	644	705	779	28
		CW	682	722	676	740	8
SP Gr 37	2,225	PAC-5	484	507	449	580	20
	2,407	CW	421	474	461	543	29
SP Gr 38	1,125	PAC-7	476	490	--	679	43
		CW	511	593	--	577	13
SP Gr 45	1,435	PAC-5	750	720	678	724	0
		CW	814	750	718	770	0
SP 54-140	2,660	PAC-5	596	642	591	595	0
		CW	547	708	610	686	26
IT Gr 14	50	PAC-7	--	--	--	--	--
		CW	--	--	--	--	--
		RT-12	--	--	--	--	--
IT Gr 22	75	PAC-7	--	--	--	--	--
		CW	--	--	--	--	--

[a] Urban.
[b] Rural.

change of roughness index) greater than the test sections. Two other projects indicated a slight improvement as designated by a lowering of the roughness index—without any significant differences between the test and control sections.

SUMMARY OF 2-YEAR EVALUATION

The Research Division of the Kentucky Department of Highways observed the construction and evaluated the 2-year performance of 10.2 miles (13 test sections) of roadway using the experimental Curtiss-Wright binder mix and 11.5 miles (13 control sections) of pavement surfaced with standard asphaltic binder mixes.

The characteristics of the material as observed during construction were cited earlier in the report. The following is a list of characteristics of the material noted during the period of observed performance:

1. The experimental material lacked flexibility; edge cracking developed rapidly; old surface and base failures soon reflected through it; and raveling and loss of the fine aggregate produced a rough-textured surface.
2. The Curtiss-Wright binder mix did not bond with itself or other paving mixes after the "set"; therefore, the cold centerline and transverse construction joints soon opened.
3. Raking and handwork on the surface and approaches were difficult and ineffective.
4. Surfaces made with Curtiss-Wright binder mix had a tendency to become more slippery than those made with standard asphaltic mixes, but the actual magnitude of the difference in coefficients of friction is very small.
5. Curtiss-Wright mix deteriorated in regard to roughness more quickly than the standard asphaltic binder mixes.

Some of these difficulties have been observed in the standard asphaltic binders, but they have not developed to such a severe degree. It appears to date that in 11 out of the 13 cases there has been a greater amount of surface deterioration in the Curtiss-Wright binder test sections than in the companion control sections.

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