COAL-IN-TAR DISPERSIONS AS HIGHWAY CONSTRUCTION MATERIALS

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Introduction

When bituminous coal is digested in a mixture of coal tar pitch and high-boiling tar oil, at temperatures in the approximate range of 300-320 C., little or no chemical decomposition of the coal occurs and the coal-modified pitch, which appears to be a colloidal dispersion of the coal as coal in the pitch-oil mixture, has temperature susceptibility characteristics better than those of the original pitch, i.e., it softens less at elevated temperatures and hardens less as temperatures are decreased.

For about thirty years coal-modified pitches have been used very successfully as hot-applied enamels for the protection against corrosion of steel structures, marine piling and underground pipe lines for the transmission of oil, gas and water. Because of their superior temperature susceptibilities they are better for such purposes than coal tar enamels made by usual procedures.

Less successful have been various attempts to use coal-in-tar dispersions for other purposes for which it might be expected - because of their improved temperature susceptibilities - that they would be better than coal tar or asphaltic materials ordinarily used for such purposes. Of particular interest in this connection are some major efforts that have been made in Great Britain and, most recently, in South Africa and the United States to employ coal-modified tars as binders for bituminous highway pavements.

Bituminous Road Binders - Tar vs. Asphalt

Binders used in pavements of the bituminous concrete type are made either from petroleum, by the vacuum or steam reduction of petroleum residuals, or from coal tar by straight distillation to the required consistency or the fluxing of coal tar pitch with tar oils. In the United States unfilled hot-mix binders of petroleum origin are called asphalts, paving asphalts or asphalt cements whereas in Great Britain and various other countries they usually are referred to as bitumens, asphaltic bitumens or petroleum bitumens to distinguish them from natural or synthetic mixtures of bitumens and fillers that are called asphalts. In the following discussions unfilled asphaltic binders will be designated as paving asphalts or asphalt cements. Coal tar binders, made either by straight distillation or the fluxing of pitch with tar oils, will be designated as tar cements.

In general, asphalt cements have better temperature susceptibilities and are less volatile at mixing, paving and atmospheric temperatures than tar cements. On the other hand, tar cements have better adhesion to most road aggregates on prolonged contact with water; are more resistant to chemical alteration by water; are dissolved or softened less by petroleum lubricating oils, jet fuels and gasoline; produce more permanently skid resistant pavements and are not as susceptible to age hardening within pavements that are densely graded or tightly sealed so that oxidation or evaporation of the binder is minimized.

Experience, both in the United States and abroad, has shown that excellent pavements of the bituminous concrete type can be constructed either with asphalt cements or with tar cements. However, different mixing and paving techniques are required. For example higher aggregate drying and mixing temperatures are needed when asphalt cements are used to insure substantially complete removal of all moisture from the aggregate and to fluidize the asphalt cement sufficiently to insure rapid and thorough coating of all aggregate particles. Lower temperatures should be used for tar cements to avoid excessive volatilization of tar oils with consequent hardening of the binder. With tar cements it is possible to use lower aggregate and mixing temperatures because they will tolerate considerably more moisture in the aggregate than asphalt cements. Also because tar cements are sufficiently fluid at the lower temperatures to insure satisfactory mixing and paving operations.

Another important difference in the preferred construction techniques for pavements containing tar or asphalt cements has to do with aggregate gradations. For best results, tar cements should be used with densely graded aggregates so that the finished pavements will be substantially voidless (3-5% residual air voids). Should a slight excess of tar binder in the mixture cause flushing of binder to the surface, the thin film of tar cement, on hardening, will be worn off by traffic. This will expose the angular particles of aggregate to produce a skid-resistant pavement surface. Because of the density of the compacted mixture, evaporation of oils from thin tar films below the pavement surface is prevented and little or no alteration of the tar binder occurs. On the other hand, a somewhat more open aggregate gradation may be used with asphalt binders. If sufficiently dense mixes are used so that flushing occurs, this must be held to a minimum to avoid the development of slippery surfaces when wet.

Methods For Improving Tar and Asphalt Binders

Various methods have been used or tried with a view to improving both tar and asphalt binders. In the case of asphalt cements such efforts have been directed mainly toward better adhesion to aggregates in the presence of water by the admixture of certain chemicals or tar oils, greater skid resistance by the addition of coal tar pitch and less "age hardening" through the use of better manufacturing procedures including the selection of raw materials.

Efforts to improve tar cements have been directed almost entirely toward the improvement of their temperature susceptibilities. The method most commonly employed, especially in Great Britain and Germany, has been the addition of paving asphalts to tar cements. Usually the asphalt content of such mixtures has been about 15 - 25 per cent but as high as 40 per cent has been used with some mid-temperature coal tars such as are produced by vertical retorts. In the latter case some improvement in binding capacity as well as temperature susceptibility is expected. As yet, this method has not been used extensively in the United States, largely because the asphalt cements produced in this country vary widely with respect to compatibility when mixed with tar cements derived from high-temperature, coke oven coal tars. When stored and used at the high temperatures employed at hot-mix paving plants such mixtures may or may not segregate or sludge depending upon the type of petroleum from which the asphalt was derived and the method of reduction used in its manufacture.

The addition of small amounts of synthetic rubber to coal tar cements is another method that has been used to some extent for improving their temperature susceptibilities. They have been used most extensively at airports where asphalt surfaces have been damaged excessively by jet fuel spillage. Aprons or runways constructed with rubberized tars, in addition to being jet-fuel resistant, deform less at high temperatures and are less likely to crack at low temperatures under heavy loads and impacts. However, the addition of rubber to the tar does not reduce its volatility and the rubberized tar binder must be stored and used at the lower temperatures recommended for usual tar cements.

Another possible method for improving tar cements is the one that will be reviewed in this paper, namely, coal-in-tar dispersion.

The Dispersion of Coal as Coal In Tars and Oils

The fact that coal as coal, at temperatures below those at which chemical decomposition of the coal begins, can be dissolved or colloidally dispersed in cyclic hydrocarbons such as coal tar, water gas and oil gas tars, or chemicals, oils and pitches derived therefrom was recognized, almost forty years ago, by Harold J. Rose and William H. Hill. From investigations started about 1924 in the Mellon Institute laboratories of the Koppers Company, Pittsburgh, Pennsylvania, they found that at digestion temperatures preferably in the approximate range of 300 - 320 C, bituminous coal appears to dissolve in tars and tar oils, or their combinations, without chemical decomposition of the coal. The end product is a pitch-like material which, depending upon the kinds and proportions of ingredients used, may have temperature susceptibilities substantially better than those of pitches made from coal tar, water gas tar or oil gas tar by usual distillation procedures. Presumably, as the digestion product cools to atmospheric temperature, the coal, which had dissolved in the digestion medium at the digestion temperature, comes out of solution to form a gel-like, colloidal dispersion of the coal in which, except for insoluble mineral ash, no particles of the original lump or pulverized coal are visible with a microscope at magnifications of 400 - 500.

The laboratory investigations of Rose and Hill resulted in the issuance of several United States and foreign patents to them with assignment to The Koppers Company. Their first patent[1] of this kind was issued in Great Britain in 1928. The laboratory studies were followed by extensive pilot plant and field investigations in which the Research Division and the Tar Products Division of The Koppers Company collaborated. Many possible outlets for coal-in-tar dispersions were investigated but most successful was the development by Koppers of superior enamels and coatings for steel structures, marine piling and transmission pipe lines for oil, gas and water. Their superiority over other coatings used or proposed for use on buried pipe lines was established by service tests conducted jointly by The American Petroleum Institute[2], The American Gas Association and The U.S. Bureau of Standards. In those tests, which were started in 1930 and concluded ten years later, pipe nipples coated with the various test materials were buried at fourteen locations in the United States and specimens were inspected at yearly intervals. Koppers' coal-digestion product, designated as Komac, behaved so favorably that its commercial production was started by the Wailes, Dove, Hermiston Corporation, maker of Bitumastic enamels and coatings, following the disclosure of manufacturing procedures to them by Koppers. Other commercial uses for coal digestion products were tried, less successfully, by the Koppers Company but they did not include highway construction or maintenance materials, except for a few field tests that were made with coal digestion pitches as brick and concrete pavement joint fillers. The first efforts to use coal-in-tar dispersions as road construction materials were made in Great Britain.

British Experiments with Coal-modified Tar Road Binders

In 1929 a British patent[3] was issued to the South Metropolitan Gas Company, London, (Pickard and Stanier) on a process for making a tar product with improved "temperature-mobility" characteristics. As in the case of the British patent[1] issued to Rose and Hill (Koppers) in 1928 the process consisted in dispersing coal in tar at about 300 C but the South Metropolitan Gas Co. patent was directed specifically toward making an improved road material or a substitute for mixtures of tar and asphaltic bitumen (paving asphalt) for road-making and like purposes by dispersing not more than fifteen percent of bituminous coal in coal tar. Tar suitable for the purpose was made either by partial distillation of crude coal tar to drive off lighter oils which would be lost during the digestion process at approximately 300 C or by distillation of the crude coal tar to pitch and subsequent adjustment of the latter by the addition of tar oils.

A second British patent[4] was issued to South Metropolitan Gas Company (Herbert Pickard) in 1930. It claimed the mixing with stone of a tar binder of the coal dispersion type described in the preceding patent to produce a road surfacing mixture of the hot-mix, hot-lay, asphaltic concrete type.

Detailed information gained from their investigations was furnished by Evans and Pickard in a treatise[5] published by South Metropolitan Gas Company in 1931. It contained a large amount of valuable information about (1) The Relationship Between Temperature and Consistency of Coal Tar (2) The Preparation Of Asphaltic-Like Substances From Coal Tar and (3) The Consistency of Pitch-Like Substances.

According to personal communications recently received by the author, additional experiments involving the use of coal-in-tar dispersions were made in Great Britain in 1945 by the South Eastern Gas Board (formerly known as South Metropolitan Gas Company). As in the earlier experiments, the purpose of the tests was to substitute coal-in-tar dispersions for tar-asphalt blends for dense tar surfacings. Asphalt suitable for the purpose was expensive and in short supply at that time, but shortly thereafter it became more plentiful again and work on the coal dispersion binders was discontinued.

Also, according to personal communications, the Coal Tar Research Association of Great Britain made additional tests in 1956 that were directed toward the improvement of tar binders for use in dense surfacings on airfields. Coal was digested in a mixture of coal tar pitch and topped coke oven tar heavy oil. Laboratory tests were said to be encouraging but, when small test sections of pavement were laid, fuming was reported to be somewhat excessive and large scale service tests were not attempted.

Coal-Modified Tar Binder Experiments in South Africa

In a paper[6] published in October 1959, Dr. H. Karius and Dr. E. J. Dickinson reported the results of investigations which they had conducted in Pretoria, South Africa as a part of the program of research of the Bituminous Binder Research Unit, National Institute for Road Research. The purpose of the work was "to find means of decreasing the temperature susceptibility of viscosity and the brittleness at low temperatures of road tars derived from steel works coke-oven crudes at least to the level of that of straight-run petroleum bitumens". Concerning coal-in-tar dispersions, their observations may be summarized as follows:

1) Road binders with temperature susceptibilities of viscosity and brittleness at low temperatures similar to those of bitumen (asphalt) resulted from the digestion of certain types of South African coal in tar especially in concentrations of 10 - 15 percent by weight.

2) The combined effect of coal and synthetic rubber on tar or pitch is greater than the sum of their separate effects. With coal present, the amount of synthetic rubber needed to equal the flow characteristics of asphalt is minimized or, by dispersing both coal and synthetic rubber in tar or pitch, flow characteristics superior to those of asphalt are obtainable. However, when coal is present it is necessary to add a substantial amount of high-boiling coal tar oil to reduce the viscosity of the dispersion when it is to be used for road construction purposes.

3) Either the GR-S (styrene-butadiene copolymer) or the Buna N (butadiene-acrylonitrile) type of synthetic rubber may be used in conjunction with coal to improve the rheological properties of tar but the GR-S type must be added in latex form.

4) Synthetic rubber, especially of the Buna N variety, when added to pitch-asphalt mixtures, appeared from laboratory tests to act as a stabilizing agent so that any pitch-to-asphalt ratio might be used without causing incompatibility in the heated mixture. Also heat-stable pitch/oil/coal/asphalt/rubber blends were prepared by mixing a coal/pitch/oil blend with a rubber/asphalt blend. Both natural rubber latex and Buna N latex were used in this manner.

Heat stable blends of the types mentioned above were described in a South African patent application[7] filed in June 1958 by Karius and Dickinson and assigned by them to the South African Council for Scientific and Industrial Research.

During and after the laboratory investigations of Karius and Dickinson, single-seal applications of tars and asphalts, with and without the addition of coal and polymers, were made on highways near Pretoria so that they might be compared and evaluated under actual service conditions. Reports on the outcome of those field tests have not yet been published.

American Investigations of Coal-Modified Tar Road Binders

Curtiss-Wright and Kentucky Highway Department Tests

The most recent attempt to develop improved binders for bituminous concrete pavements by the dispersion of coal in tars and oils was made in the United States. In the Fall of 1958 the Curtiss-Wright Corporation, whose research and development laboratories were located at Quehanna, Pennsylvania in the heart of a bituminous coal mining region, decided to explore this possibility after conferring with members of the U.S. Bureau of Mines, Bituminous Coal Research Inc. and others. Because of the successful use of coal-in-tar dispersions as pipe line enamels, which the Koppers Company was known to have developed following the researches of Rose and Hill, it was thought that similar techniques could be employed for the production of improved road binders.

Curtiss-Wright was aware of the early work along similar lines that was done by the South Metropolitan Gas Company in England but was not aware of the more recent experiments by the South Eastern Gas Board and by the Coal Tar Research Association in Great Britain or by Karius and Dickinson in South Africa.

Articles describing those investigations had not yet been published. In fact, nothing was found in the literature which would indicate that anyone had commercially produced satisfactory coal-modified tar binders for highway construction purposes.

Laboratory tests which began at Quehanna in January 1959 were continued, without interruption, for almost two years. During the latter half of 1959 they were supplemented by pilot plant and full scale highway service tests in Kentucky in which the Curtiss-Wright Corporation and the Kentucky State Highway Department collaborated. The laboratory work at Quehanna and also the design, construction and operation of the Kentucky pilot plant was, for the most part, directed by Mr. S. H. A. Young, Chief Development Engineer of the Curtiss-Wright Research and Development Department; the Project Leader at Quehanna during most of the two year period was John Horai; Frank Soriero was manager, for Curtiss-Wright, of the pilot plant and field operations in Kentucky and E. O. Rhodes assisted Curtiss-Wright in a consulting capacity both at Quehanna and in Kentucky. The Kentucky mixing and paving operations were supervised by the Highway Research Laboratory, Kentucky Department of Highways, of which Dean D. N. Terrell was the Director and Mr. W. B. Drake the Associate Director. An independent study and evaluation of the various binders produced and used in the Kentucky experiments was made in Washington, D. C. by The U. S. Bureau of Public Roads. The results of the Quehanna, Kentucky and Washington investigations were reported at the 41st annual meeting of the Highway Research Board, Washington, D. C. in January 1962 in preprints of papers by Rhodes[8], Drake[9], and Halstead, Oglio and Olsen[10]. Following is a condensed summary of the information furnished by Rhodes concerning the Quehanna and Kentucky experiments.

Preliminary Quehanna Investigations

During the first six months of 1959 many laboratory tests were performed by Curtiss-Wright at Quehanna, Pennsylvania in which coal dispersions were made with different coals, tars and oils under varying conditions of time, temperature and pressure. From a large number of formulations tried, two were selected for comparison with a typical 70-85 penetration asphalt cement and with a representative sample of tar cement meeting ASTM specifications for RT-12 grade road tar. The latter was made by straight distillation of high temperature, coke oven coal tar. One of the coal dispersions, (CW-II), contained 10.8% bituminous coal from the Freeport seam near Quehanna, Pa. and 89.2% of the RT-12 tar cement. The other (CW-III) contained 11.4% Freeport seam coal, 64.4% RT-12 tar cement and 24.2% high-boiling coal tar oil (m. m. t. 5% distillate to 315 C and 70-75% residue at 355 C). In each case the coal, dried and pulverized to pass 100% through a 100 mesh sieve, was mixed with the RT-12 road tar or RT-12 plus high-boiling coal tar oil, the mixture was heated, with agitation, to 600 F (315.5 C), maintained at that temperature for one hour, cooled to 400 F and withdrawn from the autoclave into containers. The autoclave was vented to the atmosphere throughout the run. Neither pressure nor reflux was required to obtain complete dispersion of the coal in the tar or mixture of tar and oil.

Laboratory tests indicated that each of the coal-modified tar cements (CW-II and CW-III) should be superior to the 70-85 penetration asphalt cement with respect to insolubility in jet fuels and also adhesion to aggregates in the presence of water; furthermore, it appeared that they should be superior to the RT-12 grade tar cement but somewhat inferior to the asphalt cement from the standpoint of volatility at usual asphalt mixing and paving temperatures. (225-325 F).

Comparative tests on Marshall briquets made with the various binders gave the following results:

Marshall stabilities at 140 F of briquets made with the coal-modified tar cements (CW-II and CW-III) were approximately 50% higher than those of the asphalt briquets and 100% higher than the stabilities of RT-12 briquets.

Immersion in water for 96 hours at 120 F caused the Marshall stabilities of briquets made with CW-II, CW-III and RT-12 to increase 9%, 88% and 14% respectively whereas the stabilities of the asphalt briquets decreased 17%.

After heating for 72 hours at 140 F the stabilities of briquets containing CW-III decreased only 3% and impact resistance at 32 F increased 32%. The stabilities of the asphalt briquets decreased 20% and their impact resistance at 32 F decreased 26%.

The jet fuel solubility of the CW-III briquets was only 2% as compared with 38% for the asphalt briquets.

The asphalt briquets were somewhat superior to those made with coal-modified tar binders with respect to impact resistance at 32 F and evaporation loss on heating for 72 hours at 140 F.

On the whole it appeared from the preliminary Quehanna experiments, that improved binders for bituminous concrete pavements could be made by the modification of a standard grade of coal tar cement (RT 12) with bituminous coal or bituminous coal and high boiling coal tar oil. Public announcements to the effect were made by Curtiss-Wright in April 1959 and shortly thereafter they contracted with the Commonwealth of Kentucky to produce 150, 000 gallons of coal modified tar cement for experimental use in that state.

Kentucky Pilot Plant

A pilot plant to make 1500 gallon batches of coal-modified tar cement was designed by Curtiss-Wright and it was installed and operated by them at Frankfort, Kentucky during the latter half of 1959. Operation of the pilot plant was as follows: RT-12 grade road tar, pulverized Kentucky coal and high-boiling coal tar oil were transferred to a 1500 gallon digester from tank cars or tank trucks; the mixture was heated as rapidly as possible to 600 F, with agitation but without reflux, and maintained at that temperature for one half hour; by means of an internal water-cooling coil the temperature was reduced to 400 F and the finished binder was transferred to storage or transports. No major difficulties were encountered in the operation of the pilot plant in this manner.

During the construction of the pilot plant fifty four coal samples from eastern and western Kentucky coal mines were analyzed and tested on a miniature scale for digestibility in RT-12 at Quehanna. Three of the samples, selected as being representative of eastern and western Kentucky coals, were made into two and three component type binders (CW-II and CW-III). The latter were mixed in varying proportions with representative samples of Kentucky aggregates to establish the optimum binder content for Kentucky Class I hot-mixes in which they were to be used. By agreement with the Kentucky Highway Research Department a binder content of 7. 0 percent was first used and later changed to 6. 9 percent.

During the period between August 13th and November 7th 1959 one hundred and four batches of hot-mix binder, totalling approximately 150, 000 gallons were made in the pilot plant. One hundred batches (144, 000 gallons) were of the three component type (CW-III) with the following average composition, 81% RT-12, 11% high-boiling coal tar oil and 8% coal; two batches (3, 000 gallons) of the two component type (CW-II) contained 96% RT-12 and 4% coal, and two batches (3,000 gallons) contained only RT-12 which was heated to 400 F in the digester before delivery to test sites.

Kentucky Field Tests

The CW-III type binder was delivered to fourteen test sites in various parts of Kentucky. At twelve of the sites the binder was used in 1-1/2 inch Kentucky, Class I overlays on existing black top pavements which, for the most part, had required a large amount of maintenance because of base failures or the development of slippery-when-wet surfaces. At the other two test sites the CW-III binder was used in hot-mix that was laid 2-3/4 inches thick over tar-primed soil roads in accordance with Kentucky, Class I Modified Base specifications.

The CW-II type binder was used at only one location (8 miles south of London) in a 1-1/2 inch overlay of the Class I type.

The RT-12 road tar was used in a short 1-1/2 inch Class I overlay at the above location and also in a 2-3/4 inch, Class I, modified base near Bowling Green for comparison with the CW-III type of binder.

The hot mixes were made in eleven commercial, hot-mix plants of which six were batch and five continuous. No major difficulties were encountered at any of them in the use of the coal-modified binders. Also, except for somewhat excessive fuming when paving temperatures exceeded 260 F, paving operations by nine different contractors were very satisfactory even though atmospheric temperatures varied from about 27 F to 100 F during the construction period.

However, service results from the various test pavements were not entirely satisfactory. After the first winter, which was unusually severe, considerable surface abrasion, (due in part to tire chains), and cracking was observed particularly at center joints and near the edges where the new overlays projected beyond the original pavement surfaces. Cracking was particularly noticeable at locations where the 1-1/2 inch overlays were placed on old and unstable black top pavements that had required extensive maintenance in former years. It was obvious that the overlays containing the CW-III type binder (coal, RT-12 and high-boiling oil) were too hard and brittle and did not have enough flexibility, particularly at low temperatures, for use over unstable pavements.

At the one location (8 miles south of London) where overlays containing asphalt, RT-12, and each type of coal-modified tar binder (CW-II and CW-III) could be compared under identical conditions, it appeared that the one containing only RT-12 was least satisfactory because of excessive bleeding during summer months, the section containing CW-III binder (coal, RT-12 and oil) was too brittle and inflexible and the section containing the CW-II binder, (4% coal plus 96% RT-12) compared most favorably with the asphalt control section. It appeared to have more flexibility and less brittleness at low temperatures and a greater tendency to "self-heal" in hot weather, without bleeding excessively, than the CW-III binder made with 8% coal, 81% RT-12 and 11% oil.

Soon after the test sections were laid it was apparent that the coal-modified binders should have been somewhat softer, i.e., their initial ASTM penetrations at 25 C should have been higher, a somewhat greater proportion of each should have been used in the hot-mixes, and lower mixing and paving temperatures should have been used to minimize hardening due to the evaporation or sublimation of some of the tar oils. With a view to making further improvements, the Quehanna investigations were directed along the following lines during most of 1960.

By comparing the absolute viscosities, at different temperatures, of the four binders used in Kentucky it was concluded that mixing and paving temperatures in the range of 200 - 250 should be adequate for coal-modified binders of the CW-II and CW-III types.

Ten percent dispersions of coal in RT-12 were made with a large number of coal samples from various locations in North America, South America and Japan. Their softening points (R & B) varied from 40C to 65C but they all appeared to have approximately the same temperature susceptibilities in the range of 25 to 32C. For these tests, 25 gram portions of each coal were dispersed in 225 grams of RT-12 by heating the mixture, with agitation and reflux of condensible vapors, to 600F for one hour. The results were comparable to those obtained from Quehanna autoclave and Kentucky pilot plant digestions.

Low, medium and high temperature coal tars distilled to RT-12 consistency were compared as dispersing media for Freeport seam coal. The distilled low temperature tar was unsatisfactory but dispersions made with RT-12 from two medium temperature tars compared favorably with a dispersion of the coal in RT-12 from high temperature coke oven tar.

Various polymers were added to a modified coal dispersion of the CW-III type (coal, RT-12, and oil). Included in these tests were Hycar latex, natural rubber latex, reclaimed rubber, Neoprene powder, Neoprene latex, Butyl rubber, Vistanex and Thiokol LP-3. Most of the mixtures sludged or crusted on heating at 325F for five hours. Vistanex, Butyl rubber and Thiokol were best in this respect and appeared to effect some improvement in the temperature susceptibilities of the coal modified tars.

Three aromatic oils of petroleum origin were tried, in place of high boiling coal tar oil, as plasticizers or fluxes but were incompatible when the mixtures were heated.

Promising results were obtained by adding high-penetration, petroleum residuals (180 - 200 or 250 - 300) to a dispersion of coal in RT-12. Temperature susceptibilities, particularly in the range below 25C appeared to be substantially improved.

A sand blast method of test described by Rhodes and Gillander in 1936 [11] appeared to be especially suitable for measuring the brittleness of hot mix binders particularly at low temperatures.

Bureau of Public Roads Investigations

As previously stated, the U.S. Bureau of Public Roads made independent studies of the asphalt, RT-12 and coal-modified tar binders used in the Kentucky experiments. They found that the temperature susceptibility of the CW-III binder was slightly lower than that of the RT-12 but not as low as the temperature susceptibility of the Kentucky 85-100 penetration asphalt cement; the absolute viscosities of the coal-modified tar binders were intermediate between those of the RT-12 and the asphalt cement; when subjected to thin-film oven tests the losses from CW-III were somewhat lower and retained-penetrations were somewhat higher than those of RT-12 but asphalt cement was better than either in both respects; oven ageing at 140F for 30 days caused the Marshall stabilities of briquets made with the different binders to increase as follows, RT-12 439 pounds, CW-III 2248 pounds, asphalt cement 336 pounds; development of structure or reversible hardening took place to the greatest extent in the coal modified binder (CW-III), to a lesser extent in the

64. asphalt cement and, apparently not at all in the RT-12 when thin films of each were sealed between glass plates and heated at 110 F for 13 days; immersion of quartzite briquets in water at 120 F for 18 days caused those containing CW-III to lose 8% in strength and to swell 0.2% whereas decrease in strength for asphalt briquets was 44% and swell amounted to 1.4%; unconfined compression tests indicated that the coal modified tar binder should provide higher stabilities than the asphalt cement at any temperatures encountered in service. At 0° F the stabilities of specimens containing RT-12 and CW-III were about double the stability of the asphalt specimens and were in the range of strength of Portland cement concrete. In general the Bureau of Public Roads report concluded that coal-modified tar binders, such as those made by Curtiss-Wright, should be considered as improved tars that would be expected to perform better than unmodified tars in a number of applications but normal precautions should be employed when using them rather than attempting to substitute them for penetration grade asphalts.

Conclusion

Although major efforts have been made in Great Britain, South Africa and the United States to use coal-in-tar dispersions as highway construction materials, commercial success has not yet been achieved. A large amount of important information has been contributed by the investigations conducted to date but additional work is needed particularly along the following lines.

Methods for determining the temperature susceptibilities and, particularly, the brittleness at low temperatures of bituminous, hot-mix binders that have been used by previous investigators in this field should be compared and, if necessary, a new method should be developed. A few tests by Curtiss-Wright indicated that a sandblast method might be especially suitable and additional tests should be performed. Also better methods for evaluating and comparing hot-mixes containing asphalt and coal-modified binders should be selected or developed in order, by means of laboratory tests, to predict most accurately the service lives of the finished pavements.

Formulations for road binders of the coal-dispersion types should be further improved. Most needed in this connection are better and less expensive plasticizers for use in place of high-boiling coal tar oil. Some of the materials which should be considered in this connection are water-gas and oil-gas tars and distillates therefrom, low-temperature and mid-temperature tars and tar oils and also petroleum distillates, extracts and residues. High boiling oil from heavy water gas tar is known to have good possibilities in this connection and tests made by Karius and Dickinson and also by Curtiss-Wright indicated that soft (high-penetration) asphalts should be especially interesting.

Continuous, rather than batch digestion of coal should be tried. Heretofore batch methods have been used exclusively for the commercial, pilot plant and laboratory dispersion of coal-as-coal in tars and tar oils. However, finely pulverized coal dissolves so rapidly and completely that continuous digestion with inexpensive equipment should be practicable.

Also the use of coal modified binders in highway subgrades and bases as well as surface courses should be tried. Because of the high strengths of mixes containing them and because of their extreme resistance to destruction by water, superior adhesion to aggregates and ability to penetrate soils and damp or dusty aggregates, coal dispersions made with coal tars and tar oils should be especially suitable for subgrade and base stabilization whereas coal-in-tar dispersions containing materials such as high penetration asphalts might be more suitable for use in surface courses.

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