

BITUMINOUS ROADS AND PAVEMENTS AND THEIR MATERIALS OF CONSTRUCTION.¹

BY

PRÉVOST HUBBARD,

Chemical Engineer, Institute of Industrial Research, Washington, D. C.

THE subject upon which I have been invited to speak is so broad that a large sized text-book would be required to cover, even in abstract form, the information that has so far been obtained by engineers and chemists engaged in bituminous road and paving work. It is evident, therefore, that the present discussion must be limited to a few fundamental principles if the entire subject is to be covered.

Notwithstanding the enormous amount of bituminous road and paving work that has been done in this country, the majority of highway engineers to-day are far from feeling satisfied that they can successfully meet in an economical manner the problems which modern conditions have imposed. To a great extent this is due to their lack of information regarding the physical and chemical characteristics of the materials which they are obliged to use, and to a reluctance on the part of many municipalities to incur the expense of expert inspection of these materials. It is safe to say that no type of work requires more careful nor more constant inspection than that involving the use of bituminous road and paving materials, and until such inspection is generally adopted the use of these products will never pass beyond the experimental stage. The reason for this must be apparent when the widely-varying nature of the bitumens themselves is considered.

No sharp distinction can be made between the terms roads and pavements. This is especially true at the present time, owing to the fact that many materials of construction are common to both, and in suburban roads in particular the methods of construction often approach very closely, or are identical with, the methods of constructing certain types of city pavements. In general, however, roads may be considered as highways, improved

¹ Presented at the meeting of the Mechanical and Engineering Section, held February 29, 1912.

or unimproved, which mainly occur in rural and suburban districts, and pavements as highways occurring mainly in cities and towns. Roads are usually constructed of earth, gravel, or broken stone, with or without the addition of special binding material. In the more advanced types but little attention is paid to grading the aggregate. Pavements, on the other hand, are constructed of sand or broken stone bound with an hydraulic or bituminous cement and often of a mixture of three or four constituents carefully graded and proportioned before mixing. In addition, regular sets of brick, stone block, asphalt block, and bituminized or creosoted wood blocks are also employed. At the present time great variations in methods as well as materials of construction exist, and because of this fact absolute standards which will successfully meet all conditions are an impossibility. The problems encountered in road and paving construction are so numerous and so involved that the services of experts who have specialized in this field have come to be almost a matter of absolute necessity where work of any magnitude is undertaken except in a purely experimental manner. And even where the work is of an experimental nature expert advice and inspection are necessary to obtain information of greatest value, upon which future work may be based.

Bituminous roads and pavements may be conveniently divided into seven groups: (1) bituminous earth roads, (2) bituminous gravel roads, (3) bituminous macadam roads, (4) bituminous concrete pavements, (5) sheet asphalt pavements, (6) asphalt block, and (7) bituminized wood block pavements. All of these groups are sharply defined with the exception of the bituminous macadam and bituminous concrete, which overlap each other according to the method and degree of refinement used in construction. Bituminous earth, gravel, and broken stone roads may be either constructed in such manner that the bituminous binder is incorporated in the road proper, or only a surface application of the bitumen may be given to the otherwise completed road. In the last four types bitumen is always incorporated with at least a portion of the paving material, and usually before placing it. Whether in surface treatment or construction, selection can be made from a great variety of bituminous materials, and these materials may be applied or used according to many different methods.

The selection and use of bituminous materials for the types of roads and pavements previously mentioned may best be discussed after considering the characteristics of the bitumens themselves.

In the broadest sense bitumens may be defined as mixtures of native or pyrogenous hydrocarbons and their derivatives, which may be gases, liquids, viscous liquids, or solids. If solids, they soften more or less readily upon the application of heat and are soluble in certain organic solvents. They may be conveniently divided into two main classes: (1) native bitumens and (2) artificial bitumens. Native bitumens, as their name implies, occur in nature, and often contain impurities, such as water, clay, silt, sand and extraneous organic or vegetable matter. Those of interest as road materials are petroleums, malthas, asphalts, and other solid products of an asphaltic nature, such as Gilsonite and Grahamite. Artificial bitumens are distillates and residues produced by the partial or fractional distillation of bitumens, pyrobitumens, and other organic materials, such as wood or bone. Manufactured petroleum residuums, oil asphalts, asphaltic cements, coal tars, water-gas tars, and tar distillates are the most important members of this class from the stand-point of road and paving work.

Both crude native and artificial bitumens are almost invariably refined before they are used in highway treatment or construction. The refining process may consist in a separation of some of the constituents present, either by sedimentation or distillation. A third process, known as fluxing, is also employed to a large extent in the preparation of the finished product. With few exceptions, crude bitumens contain water, and the crude native products carry extraneous mineral and organic matter as well. If the material is sufficiently fluid, as in the case of many crude petroleums and tars, much of the water may be removed by natural separation in large storage tanks or wells. Here the water gradually collects at the bottom where petroleums are stored, and also mineral matter if it is present. In the case of tars the water rises to the top, owing to the greater density of such materials. If the crude material is extremely viscous or semi-solid, heat may be required to effect the separation. Native asphalts are thus refined by heating them in large tanks or kettles until fluid, when the water and extraneous organic matter col-

lect at the top and are skimmed off, while the mineral impurities collect at the bottom.

In the manufacture of dust preventives and binders from bitumens, consistency is one of the most important physical properties to be considered, and this property can be controlled by distillation or fluxing. Thus a fluid petroleum or tar may be brought to any desired degree of solidity by distilling off the proper portion of the more volatile constituents. If the distillation is accompanied by blowing air through the hot material, the desired degree of solidification may be brought about at a lower temperature than by straight distillation and the yield of residue increased, but such effect is produced by certain chemical changes in the material proper, and not by merely removing the more volatile products. This method is known as the blowing process, and the materials produced are said to be blown products. They are characteristically short or non-ductile.

Fluxing consists in mixing or combining a hard or solid bitumen with one that is more fluid, called the flux. This combination is usually facilitated by the application of heat and mechanical agitation. Fluxing may serve one of two purposes: a hard bitumen may be softened to the desired consistency by the addition of a fluid bitumen, or a viscous bitumen may be reinforced or hardened by the addition of a solid bitumen. Thus it is customary to soften a refined native asphalt with a fluid petroleum residuum and also to reinforce very viscous blown petroleum residuums with such products as Gilsonite, which are hard and solid.

The following diagram gives a graphic representation of the principal types of bituminous road and paving materials as produced by the processes mentioned, also of products formed simultaneously with their manufacture.

It will be noted that the crude materials are divided into three general classes—petroleums, asphalts, and tars—which are all subjected to the process of sedimentation before further use, in order to remove water and other impurities in so far as possible. Distillation is the second process involved in the preparations of petroleum and tar products, and in each case two classes of products are formed—distillates and residues. This distillation results mainly in a fractionation of the material, and the more volatile constituents or distillates are thus separated from

P

Mineral Matter nical
 er

Distillates ies

Water ted Tars

Naphthas ined Tars

Burning Oils ofined Tars

Gas Oils fined Tars

aight

Lubricating Oils own

Paraffine

Road Oils hes
(Dust Preventives)

ke

Cut

the less volatile residues. When fractional distillation is employed the distillates are oils or greases and possess no binding value. The true binding constituents, if present, are always to be found in the residues, and these residues are used to a great extent as binders for road and paving work.

As previously stated, the consistency of a residue may be controlled by the quantity of distillate removed. Sometimes the residue, while otherwise satisfactory, is harder than can be readily employed according to a given method of construction. For instance, an oil asphalt or heavy refined tar, while suitable for the preparation of a bituminous concrete, cannot be mixed with cold stone. When this is so the material is sometimes fluxed with one of the lighter distillates which have previously been removed, and the resulting product is said to be cut back. The oil or tar residue is thus brought to any desired degree of fluidity necessary to facilitate cold mixing, and the distillate is expected to act only as a temporary flux. If sufficiently volatile, it will, in the course of time, evaporate and leave the original residue as the permanent binding material.

Refined asphalts and other solid native bitumens of an asphaltic nature are often too hard for road or paving work. Permanent fluxes, such as the fluid non-volatile petroleum residues, are therefore incorporated with them to produce asphalt cements of desired consistency. Various combinations of petroleum residuums with tar products may also be made with the formation of what are known as tar-asphalt compounds. Emulsions may be produced from nearly any of the bitumens used in road and paving work by incorporating them with soap solutions in one way or another.

While distillation at comparatively moderate temperatures usually results in fractionally separating the constituents already present in a bitumen, if it is carried beyond a certain point the compounds remaining in the residue may be altered chemically. This is caused by a cracking or breaking down of certain of the constituents into products which did not exist in the original material, and the general character of the material is therefore altered. If distillation is pushed to the limit, a complete change in the residue is effected and coke is formed. In this case the process is said to be destructive. The two extreme forms of distillation are therefore known as fractional distillation and

destructive distillation. An intermediate form where chemical changes take place without the production of coke is known as cracking. It is evident that the method of distilling a bitumen will largely control the ultimate character of both distillate and residue. As applied to bitumens, the process of cracking and destructive distillation results in the formation of undesirable residues from the standpoint of their use in road and paving work.

This point may be illustrated by comparison with the very common operation of making candy from a solution of sugar in water. At first the sugar solution is a comparatively thin liquid possessing very little adhesiveness. As it is boiled, however, a portion of the water is driven off or fractionally separated and the residue gradually becomes more viscous and sticky. The formation of a syrup is thus entirely comparable with the production of a thick, viscous road oil or road tar. In the case of the sugar solution, if boiling is continued a little further more water is removed, and if the residue is allowed to cool a sticky taffy is produced which can be compared with the oil asphalts and soft tar pitches. If the solution is boiled beyond the taffy stage more water is removed and brittle candy is formed, which corresponds to the harder pitches from bitumen distillation. Now up to this point the inherent adhesiveness of the sugar solution has not been injured, and if the brittle candy is dissolved in a little water a sticky syrup will be produced. This would represent the cutting-back process before mentioned. If, however, the sugar solution is not removed from the fire at the brittle candy stage certain chemical changes begin to take place. First the solution darkens very decidedly with the formation of caramel, and the odor of burnt sugar is noticed in the vapors given off. Evidently something besides water is being removed. Sugar itself will not distil unaltered, and the product other than water which is driven off has been formed by a chemical breaking down of the sugar molecules. Here we have an example of cracking. If the solution remains much longer on the stove the entire mass swells up, intumescs, and gives off an acrid odor, and an examination of the residue when cold will show it to be black, brittle, and powdery. It has almost entirely lost its property of forming a syrup when mixed with water, and, in fact, the greater portion will not even dissolve in water, but floats on the

surface as a black deposit. In other words, its binding value has been seriously injured. If the mass is still further heated, tarry vapors are produced and only coke remains in the container. The final operation has been destructive.

In the preparation of petroleum road and paving binders, only those oils which produce residues similar to the native asphalts are of value. There are two distinct types of crude petroleum, one of which contains a greasy base or residue and the other a sticky base. They are known, respectively, as paraffin and asphaltic petroleums. Intermediate varieties which partake of the nature of both and contain a mixed base are known as semi-asphaltic petroleums. Paraffin petroleums are chemically more stable than the asphaltic petroleums, and are therefore less likely to change in character under service conditions. While these residues have little adhesive value, if sufficiently fluid they may make admirable permanent fluxes. A fluid asphaltic petroleum residue, on the other hand, may make an undesirable permanent flux, owing to its tendency to harden under atmospheric conditions and thereby to increase the hardness of an asphaltic cement beyond the proper limit for the work in which it is used. The proper selection of a flux for the preparation of an asphaltic cement is consequently a very important matter. This is also true of cut-back products, in which the flux should be either chemically unstable or readily volatile.

Certain intermediate native products, lying between the petroleums and asphalts, which are known as malthas, exhibit many of the properties of cut-back oil asphalts. They contain an asphaltic base, certain volatile constituents, and a scarcity of intermediate oils. When the lighter oils evaporate under natural conditions a semi-solid residue or asphalt is left. When malthas occur impregnating sandstone, the aggregate is termed rock asphalt. Rock asphalts have been used to a considerable extent in road and paving work.

There is almost as great a variety of solid native bitumens as petroleums. In fact, these products may, for all practical purposes, be considered as naturally produced petroleum residuums. They therefore range from almost pure paraffin compounds to asphaltic compounds. The latter only are suitable for the preparation of road and paving materials. They are, as a rule, too hard to be used for this purpose in their natural condi-

tion, and have to be fluxed to desired consistency. Under the native asphalts, such products as Gilsonite, Grahamite, and other solid native bitumens of an asphaltic nature may be grouped.

While petroleums, malthas, and the solid native bitumens are all closely related and many of them contain identical constituents, tars are an entirely different class of bitumens. They are artificial distillates produced by the destructive distillation of organic matter, such as coal, wood, bone, oil, etc. Those of special interest from the stand-point of road and paving work are produced from bituminous coal, and from gas oils which are themselves fractional distillates of petroleum. Unlike the distillates from fractional distillation, those produced by destructive distillation often possess a very considerable amount of inherent binding value. Thus the gas oils are, as a rule, essentially greasy, but if they are subjected to a peculiar process of cracking, as in the manufacture of carburetted water gas, the tar distillates which are produced may afterwards be fractionally distilled to produce characteristically adhesive residues or tar pitches.

Coal tar is a by-product of the manufacture of illuminating gas or coke from coal, and tar produced as a by-product from gas oils in the manufacture of carburetted water gas is known as water-gas tar. Although originating from two entirely different sources, they have many properties in common, and to a large extent carry identical constituents. In the crude state they always carry a considerable percentage of water, which in the case of coal tars is ammoniacal. As they are distillates, practically no mineral matter is present, but they contain more or less suspended organic matter, not bitumen, which is commonly called free carbon. The water may, to a large extent, be removed by sedimentation, and this removal is completed in the first stages of fractional distillation. Free carbon, however, persistently remains in the tar body and cannot be removed except by filtration. This is seldom if ever done in the manufacture of road and paving materials.

Coal tars may be divided into two classes, known as gas-house tars and coke-oven tars. The former, as a rule, contain a much higher percentage of free carbon than the latter, and in certain respects are less desirable for the manufacture of road binders. Water-gas tars contain only a very small percentage of

free carbon. In 1908 about 101 million gallons of coal tar were produced in this country, nearly 43 million of which were coke-oven tars. In 1910 over 66 million gallons of coke-oven tar were produced and recovered. Our possible annual supply of this type of bitumen is, however, far in excess of this figure, for it has been estimated that the enormous amount of 500 million gallons of coke-oven tars was lost during 1910, through the use of non-recovery or bee-hive ovens in which the vapors are wastefully allowed to burn upon being set free from the coal. The value of the tar thus lost amounts approximately to \$12,000,000 annually.

In the preparation of tar binders the method of distillation conforms quite closely to that followed in the manufacture of petroleum binders. For a given type of construction, however, a much softer tar residue is prepared than in the case of petroleum. This is due to the fact that the harder tar residues are much more susceptible to temperature changes than the petroleum or asphalt preparations of similar consistency, and are therefore apt to be more brittle in cold weather. A softer consistency for tar products is allowable because of their greater adhesiveness and binding value, and it is further advisable because tar binders set up or harden more rapidly through loss by volatilization or certain chemical changes which the tar undergoes on exposure to service conditions. Attempts to bring these peculiar characteristics of tars under more perfect control have been made by fluxing or incorporating them with certain petroleum products. The resulting mixtures are called tar-asphalt compounds. While the possibilities of such mixtures are great, and encouraging results have in certain cases attended their use in road construction, there is much yet to be learned regarding them. Unless carefully made, with just the proper grades and proportions of each, the combination of tar and petroleum products to form a satisfactory road material is by no means assured, and a considerable amount of research will be required to perfect the tar-asphalt compounds. Frequent failures have resulted from the indiscriminate mixture of these materials by engineers not familiar with the physical and chemical properties of each. In the author's opinion, the fundamental cause of these failures is due to the fact that, while some of the lighter constituents of tars are good fluxes for petroleum bases, petroleum oils are poor fluxes

for tar residues, and often act as precipitants of these bases with the formation of a crumbly, non-adhesive mixture.

One of the constituents of tars which is of considerable interest in connection with road and paving materials is naphthalene. This product is found both in the distillates and in the tar residues. It is a white crystalline substance, readily volatile, and, although solid at ordinary temperatures, it has the property of acting as a flux for the solid tar pitches. Thus a combination of two solid bodies may be made to produce a fluid mixture. It would seem that the volatilization of naphthalene from tar residues might be largely responsible for their rapid hardening under service conditions. Naphthalene also occurs in the tar distillates used for creosoting wood block. So far as the author is aware, except for the purpose of cutting back residues, tar distillates are only of value in the road and paving industries for the purpose of impregnating and water-proofing wood block. They are seldom if ever used for road treatment, as they exhibit no binding value and have but few of the characteristics requisite for a good dust preventive. Even when used in connection with wood it is a question as to whether their quality is not improved by the addition of tar residues containing low percentages of free carbon.

Having in a general way considered the preparation and characteristic properties of the bitumens used in road and paving work, their application for this purpose may be taken up. In the present paper it is hardly practicable to describe in detail the various methods of applying bitumens and of constructing bituminous roads and pavements. What results are to be expected from the use of the different types of bitumens may, however, be briefly considered.

The use of bitumens in the treatment and construction of earth roads was first tried for the purpose of reducing the annoyance and damage caused by road dust in localities where protracted spells of dry weather were of frequent occurrence. Most of this work has been carried on in the State of California, where crude native asphaltic oils of local occurrence were first applied to the road surface. The results were so successful, in so far as laying the dust was concerned, that after the first experiment had been made in 1894 the use of crude oil for this purpose advanced quite rapidly. From this work it was soon learned that so long

as the road was hard and dry it could be made dustless for a considerable length of time by a single application of oil. In rainy weather, however, the road became saturated with water, and the oiled crust broke up under traffic, producing a disagreeable mud. When the road again dried out, the dust-laying effect of the oil was to a great extent destroyed, owing to the destruction of the crust. Because of this fact, attempts were made to construct oil earth roads by incorporating the oil with the earth to a depth of five or six inches. This was accomplished by first plowing up and harrowing the road to the required depth, then applying the oil, and afterwards mixing it with the earth and consolidating the mixture by means of an ingenious device known as the sheep's foot or tamping roller. Roads so constructed were found to be almost permanently dustless, but their capacity for bearing loads was much lessened as compared with the hard dry earth, and their tractive resistance was greatly increased. The development of such roads up to the present time has shown them to be far from satisfactory under heavy hauling traffic, and when constructed in the eastern section of the United States, and, in fact, almost anywhere except in California, they have almost invariably proved failures.

There are two fundamental reasons for this lack of success, and one of these reasons is an underlying principle which has long been recognized in the construction of sheet asphalt pavements. It is, that in order to produce a satisfactory wearing surface from a mixture of bitumen and a finely-divided mineral aggregate containing particles no larger than sand grains it is necessary that the aggregate be carefully graded and that the bitumen be a semi-solid having very definite consistency limits. In other words, the tendency of the particles of a finely-divided aggregate to displacement under traffic conditions must be overcome by first making the aggregate as dense as possible, and then holding the particles together by cementing them with a tough and fairly hard bituminous binder. This is the key to the situation as regards bituminous earth roads, and because of the difficulties in meeting these requirements the outlook for this type of road is not exceedingly promising. Even if the grading of the mineral matter could be assured, the thorough incorporation of unheated earth with a melted bitumen, which congeals upon coming in contact with it, cannot be accomplished, and a more

fluid product will not produce the requisite stability. The only reason that partial success has attended such work in California is that the local petroleum is highly asphaltic and exhibit a tendency to harden rapidly upon exposure to atmospheric conditions. The absolute failures in the East are due, first of all, to the above-mentioned cause, and, secondly, to the fact that the oils used were only semi-asphaltic and possessed neither the binding value nor the tendency to harden which the California oils exhibit. As a result, these roads had little bearing capacity and rutted badly under traffic. In wet weather water was ground into the oiled earth, with which it emulsified to produce an obnoxious greasy mud to the full depth of the road. Under these conditions even the dust-laying effect of the oil soon disappeared.

With regard to bituminous gravel roads little need be said, as they are the connecting link between the bituminous earth and bituminous macadam types and partake to a great extent of the nature of both. In general, the surface treatment of gravel roads with bitumens gives more promise of success than the use of these materials in construction. Well-compacted gravel has considerable inherent stability or capacity for carrying loads without suffering displacement. A bituminous mat or crust formed on the surface of a gravel road does not tend, therefore, to break through under traffic, as in the case of earth roads. Most gravel, however, contains a large proportion of rounded water-worn pebbles which do not interlock, and, when mixed with a bituminous binder, tend to slide over one another under pressure. Unless the gravel contains a certain proportion of coarse, angular sand grains which operate to reduce such movement, the bituminous-constructed gravel road is not as apt to give satisfaction as the bituminous macadam.

Before considering the bituminous macadam road it may be well to review briefly the reason why it has become necessary, in many localities, to modify the old macadam type of construction. The principal cause is generally admitted to be a class of traffic that has within the past ten years become quite common, but which was unknown in the days of Macadam, and for which the road that bears his name was never devised. The roads of to-day are called upon to meet entirely different conditions from those formerly encountered, owing to the introduction and rapid

adoption of the automobile. Had not this new class of traffic appeared, the ordinary macadam would still be a successful type of road for country and suburban traffic, as it is well adapted to meet the conditions imposed upon it by horse-drawn, steel-tired vehicles. It has been found, however, that no ordinary water-bound macadam is capable of withstanding, for any length of time, the action of excessive automobile traffic, which tends to denude the road of all its rock dust, thus destroying the bond of the wearing surface, and then to pry loose the larger fragments of stone beneath, and so cause ravelling and disintegration. To prevent this action, recourse has been had to treating old road surfaces with bituminous materials so as to prevent the removal of dust and at the same time bind and hold in place the fragments of broken stone which constitute the body of the road.

For the treatment of old road surfaces fluid petroleum and tar residues, and also certain petroleum distillates, have been extensively used. The latter serve as dust preventives only, and in no sense as road binders, although, by moistening or oiling the dust particles on a road, they prevent to a great extent their removal by motor traffic and thus prevent the road from rapid disintegration. This effect is but temporary, and on heavily-travelled roads rather frequent applications are required. Considerable care has to be exercised to keep the rate of application within proper limits, for if an excess of these oils is used they act as lubricants for the larger stone particles and destroy the natural binding value of the rock dust, thus hastening the disintegration of the road. Moreover, an excess will produce an oily disagreeable mud in wet weather. The same is true of the more fluid, non-volatile petroleum residuums. All of the bituminous materials which are merely dust preventives can be applied cold by means of a sprinkler.

The selection and use of viscous petroleum and tar residues which are expected to act as binders, in addition to being dust preventives, require considerable judgment, and best results can only be secured by purchasing these materials under specifications and then having them systematically examined for conformity with specifications. Such products have been termed semi-permanent binders. They are employed for the purpose of forming a bituminous cushion or mat over the road surface, thus protecting it from wear. They are applied by means of specially-con-

structed distributors, either hot or cold and with or without pressure, according to their viscosity and the desired rate of application. If they do not contain a good binding base which becomes available under service conditions they are apt to prove most unsatisfactory. Even when derived from the better types of bitumens, careful selection should be made with regard to the traffic which they will have to meet.

Unlike the plain macadam road, a bitumen-surfaced macadam is less injured by motor vehicles than by horse traffic. In fact, the former class of traffic is, under most conditions, actually beneficial to a bituminous surface cushion, and were it not for the fact that mixed traffic had to be cared for, the problem of protecting our roads from the destructive action of automobiles would be easily solved. When a road is subjected to any considerable amount of heavy teaming traffic, however, the heavily-loaded steel-tired wheel and the iron-shod horse's hoofs cut through the surface mat and cause rapid disintegration. If motor traffic is equal to or greater than the horse-drawn traffic, the cuts and abrasions of the bituminous mat caused by the latter may be ironed out as fast as formed by the passage of soft rubber tires, but where the conditions are reversed the injurious action of the horse-drawn traffic is soon made apparent, especially on narrow roads during cold, rainy weather. In order to determine what material is best suited for application to the surface of a given road it is necessary to know the volume of traffic to which the road is subjected in bad weather; the proportion of horse-drawn to motor vehicles during bad weather; and the character of both classes of traffic during bad weather. Under certain conditions no form of purely surface treatment will prove satisfactory. In such cases the use of a bituminous binder during construction may be necessary.

There are two general methods of constructing bituminous macadam roads which have been largely followed in this country, one known as the penetration method and the other as the mixing method. In both it is usually considered sufficient to incorporate the bitumen with only the upper two or three inches of broken stone constituting what is known as the wearing course. The foundation may be constructed as in ordinary macadam work, but greater attention should be paid to making this course more dense and less subject to movement under traffic.

Many failures have resulted from poor foundations, which have been wrongly attributed to the use of inferior bitumens, and it is the author's conviction that substitution of Portland cement concrete foundations for the old type of broken stone foundation will prove in many cases the most satisfactory and ultimately economical procedure.

In the penetration method of construction the wearing course of broken stone is placed upon the foundation to a depth of about three inches and partially compacted by rolling before the bitumen is applied. The size of the stones should vary according to the type of rock used. For a hard rock, such as trap, material varying from $1\frac{1}{4}$ inches to $\frac{1}{2}$ inch in diameter is suitable, but when a rather soft limestone is used a coarser grade may be required. After the stone has been partially compacted, hot bitumen is distributed over the road at the rate of about $1\frac{1}{2}$ gallons to the square yard. Clean $\frac{1}{2}$ -inch stone chips are then spread over the surface in sufficient quantity to fill the surface voids and the road rolled until firm. A paint coat of the hot bitumen should then be applied and the road finished off by rolling in another coat of screenings. Application of the hot bitumen may be made either by means of pouring pots or mechanical distributors.

In the mixing method the wearing course of crushed rock is mixed with the proper proportion of hot bitumen before it is placed on the foundation. Sometimes the aggregate itself is heated before mixing, and sometimes it is used cold. The mixing may be accomplished either by hand labor or by machinery. After the bitumen-coated stone has been laid to the desired depth it is rolled either with or without the addition of a thin layer of $\frac{1}{2}$ -inch stone chips free from dust. It is finished off with a coat of bitumen and chips as in the penetration method. But little attention is paid to grading the aggregate which is mixed, and usually a single grade of ordinary commercial crushed stone is used. Mechanical mixing, when properly conducted, is preferable to hand mixing, and with the recent development in small portable mixers which warm or heat the stone before mixing, very satisfactory work can be accomplished. Heating the stone on sheet-iron plates over open fires has proven to be bad practice, as there is great danger of overheating a portion of the stone and thus ruining the bituminous binder.

The selection of a suitable binder for bituminous macadam construction is a most important matter, requiring some skill and judgment. There is no one best product for all bituminous macadam roads, and selection must be governed by a number of conditions. The principal factors to be considered are: (1) the physical characteristics of the stone which is to be used; (2) the desired method of applying the bituminous binder, *i.e.*, whether the material is to be applied cold or hot and by means of a mechanical distributor, with or without pressure, by pouring from buckets, or as a prepared mixture with the road material, and in the latter case it is also necessary to know in advance whether or not the stone itself is to be heated; (3) the quantity and character of traffic to which the road will be subjected; (4) climatic conditions; (5) the cost of bituminous material; and (6) the probable cost of application. The materials from which selection may be made are oil asphalts, fluxed native asphalts, heavy refined coal tars, cut-back oil asphalts, and tar-asphalt compounds. When the type of material is finally chosen, its physical and chemical properties should be covered by specifications. Sometimes it is advisable to make use of two grades of binder, one for incorporation in the body of a road and one for use as a paint coat. Thus under certain conditions where horse-drawn traffic is heavy it may be well to use a heavy refined tar for the wearing course and an oil asphalt for a paint coat. High carbon tars should never be used for paint coats, and fluid cut-back products, as well as certain grades of oil asphalts, are also unsatisfactory for this purpose, where horse-drawn traffic is heavy.

Bituminous concrete pavements in many respects resemble the bituminous macadam built according to the mixing method. The aggregate composing the wearing course is, however, more carefully graded so as to increase its density to a considerable extent and reduce the voids upon compaction. At least two sizes of commercial crushed rock are used, or else a single size is combined with sand in such proportions that the desired result is secured. The aggregate is almost always heated before mixing it with the bituminous binder, and the binder is usually of semi-solid consistency, approaching that of asphalt cements such as are used in the construction of sheet asphalt pavements. When these refinements of construction are employed in the prepara-

tion of the wearing surface much care should be exercised in preparing a suitable foundation, for the failure of a foundation in such pavements is apt to prove costly. Portland cement concrete should be employed in most instances. Such wide variations exist in the specific gravity of both aggregates and bitumens which may be used in this type of pavement that it is never safe to rely on weight relations in proportioning the constituents unless their volume relations are first ascertained. The actual bitumen content of the bituminous binder should also be taken into account when preparing the mix. These points may be illustrated by considering what the volume relation between bitumen and aggregate would be for two possible mixtures containing six per cent. by weight of bituminous binder. Thus the combination of a blown oil asphalt, reinforced with Gilsonite, with an aggregate of high gravity might amount to 26 gallons of bitumen per cubic yard of aggregate, while the combination of a heavy, refined coal tar with an aggregate of low specific gravity might amount to only 12 gallons of bitumen per cubic yard of aggregate.

The construction of sheet asphalt pavements requires perhaps more careful inspection of materials than any other type of road or pavement so far considered. While in the bituminous macadam and bituminous concrete construction bitumens with a wide range of consistency may be satisfactorily employed if properly selected, the same is not true of sheet asphalt. The reason for this lies in the fact that the aggregate of the former possesses considerable inherent stability, and without a binder of any sort would suffer comparatively slight displacement under localized compression if first properly compacted. The wearing surface of a sheet asphalt pavement, on the other hand, consists of a finely-divided aggregate which is largely dependent upon the bituminous binder, so far as its resistance to displacement under pressure is concerned.

The most common type of sheet asphalt pavement consists of three courses: (1) a Portland cement concrete foundation, (2) an intermediate course of crushed rock mixed with a bituminous binder known as the binder course, and (3) a wearing course composed of a mixture of sand, limestone dust or Portland cement and an asphalt cement or oil asphalt. Various modifications of construction are allowable under certain con-

ditions. Thus a well-compacted old macadam road or an old stone block pavement may sometimes be made to serve as a foundation. Where traffic is light the binder course is sometimes omitted, and the wearing course is placed directly upon a concrete foundation. When the binder course is used it may be either of the open or closed type, and so on. It is hardly possible, in the present paper, to consider the relative merits of all of the modifications of construction which may be enumerated. The wearing course may, however, be briefly discussed.

In the first place, it is absolutely essential that the aggregate of the wearing course be carefully graded so as to produce under compaction a dense mass as free as possible from voids. This is a matter which requires the most constant supervision, owing to unavoidable variations in different lots of sand obtained from the same source. Sometimes it is necessary to combine two or more sands in order to obtain the proper grading, and the proportion of limestone dust or Portland cement which serves as a filler must be increased or decreased according to variations in the sand. The proportion of bitumen which is added must also be watched, and frequent examinations of the mix must be made to determine if the proportions have been correctly made. The physical and chemical characteristics of the asphalt cement must also be kept under perfect control, and this can only be done by constant and expert inspection. Innumerable costly failures have resulted from a lack of such inspection.

The preparation of an asphalt surface mixture or topping, as it is more often called, is carried on at an asphalt plant. Quite frequently the asphalt cement is also prepared here by fluxing a refined native asphalt with a petroleum residuum flux. The asphalt is first melted in a specially-constructed melting tank, preferably heated by steam and equipped with perforated pipes for air agitation. The proper proportion of hot flux, which has previously been determined, is then run into the melted asphalt and the two thoroughly mixed until a homogeneous product has been prepared. The consistency of the asphalt cement is then determined to see that it is suitable for the work to be done. If satisfactory it is ready to be mixed with the mineral aggregate. This aggregate, composed of a mixture of selected sand, is first dried and heated in a revolving cylindrical drum, from which it is discharged and conveyed to the mixer after adding the

proper proportion of filler. Here a batch is measured out and run into the mixer, after which the proper amount of the melted asphalt cement is added and thoroughly mixed with the aggregate by means of two sets of revolving metal blades operating in opposite directions. At all stages of the mixing process it is necessary to control carefully the temperature of both bitumen and aggregate so as not to harden or otherwise injure the former. The prepared mix must, however, be sufficiently hot to be readily spread upon the street, where it is laid to the required depth and compacted by means of a tandem roller.

Little need be said in the present paper regarding asphalt block or creosoted wood block. The former is composed of a mixture somewhat similar to the sheet asphalt topping, but containing crushed rock, a portion of which is considerably coarser than the coarsest sand of an asphalt topping. The bitumen is also of harder consistency and the mixture is subjected to considerable pressure in order to produce a block which will withstand handling and transportation without breaking. Creosoted wood blocks are usually made from long-leaf yellow pine or Douglas fir. They are first sterilized by steaming, then placed in a partial vacuum to remove the moisture and gases which they may contain, after which the desired amount of creosoting oil is forced into them under pressure. The proper grade and character of creosoting oils suitable for wood-block treatment is at present an open question among engineers and chemists, some preferring a pure coal-tar distillate and others claiming that the presence of a small amount of residue in the distillate is a rather desirable feature. Lack of knowledge on the part of engineers regarding the characteristic properties of distillates and residues has often resulted in the preparation of specifications conformity with which would make it impossible to supply the product called for. Thus specifications stating that the oil must be a pure distillate are often drawn up in such form that all pure distillates are excluded and only mixtures of distillates and residues can be made to fulfil the various clauses of the specifications.

So much has been said concerning the necessity for expert inspection of materials used in bituminous road and paving work that a brief description of some of the more common laboratory methods of examination may not be out of place. There are four main purposes for which bitumens may be used in highway

treatment or construction: (1) as dust preventives, (2) as binders for coarse aggregates, (3) as binders for fine aggregates, and (4) as preservatives. The method of examination should be varied according to the type of material and the purpose for and manner in which it is to be used. The more common tests may be divided into six groups: (1) specific gravity; (2) consistency; (3) flash point, volatilization, and distillation; (4) total bitumen; (5) the action of selective solvents, and (6) miscellaneous. The first of these need not be discussed other than to state that the specific gravity of a material is often a valuable means of identifying it when taken in connection with certain other tests.

There are five commonly used tests for determining the consistency of bitumens: (1) viscosity, (2) float test, (3) penetration test, (4) ductility, and (5) melting point. The viscosity test is applied to fluid bitumens and usually consists in determining the length of time required for a measured volume of the material to flow through a tube of known diameter and length under standard conditions of temperature and pressure. The results are expressed in terms of the viscosity of water under the same conditions, or as specific viscosity. The float test is a measure of the time required for a plug of the bitumen to soften sufficiently to allow water to displace it when floated on water maintained at a given temperature. The water thus gains entrance to the float apparatus and causes it to sink. The penetration test is made by noting the distance that a No. 2 cambric needle penetrates into the sample of bitumen, vertically, without friction under a stated weight applied for a stated length of time, the sample being maintained at a given temperature. The ductility test is a measure of the distance a standard test specimen of the bitumen, having a minimum cross section of one square centimetre, will stretch without breaking when the specimen is pulled apart at the rate of five centimetres per minute. The so-called melting-point determination is made according to various methods, the object being to determine the temperature at which semi-solid or solid bitumens soften sufficiently to flow.

A determination of the flash point is useful in the examination of bituminous materials which contain any considerable amount of volatile products. The quantitative determinations of constituents volatile at certain temperatures to which the bitu-

mens may be raised during application is also of importance in order to ascertain what changes, if any, may be expected to take place in the material during application. Residues obtained from volatilization tests are therefore often examined for comparison with the material from which they are derived. Distillation tests are in a miniature way conducted according to the methods of fractional distillation employed in the manufacture of bituminous road materials, and a quantitative determination is made of the various distillates and the residues so obtained.

The determination of total bitumen is made by digesting a weighed sample of the material with carbon disulphide, which dissolves the bitumen. Any material not dissolved is then filtered off and weighed, the difference between the two weights giving the amount of total bitumen. The action of certain selective solvents, such as carbon tetrachloride, acetone, dimethyl sulphate, and petroleum naphthas, often gives valuable information concerning the characteristics of bituminous materials. These solvents do not necessarily dissolve all of the bitumen present, and a separation of certain constituents can therefore often be made by their use. Many other tests are also employed in the examination of bituminous road and paving materials which need not be mentioned in this paper, as it is impossible to describe them and discuss their application without entering into great detail.

In conclusion, it may be said that the examination of bituminous road and paving materials may be made for the purpose of identification, control during manufacture, ascertaining whether or not they conform to specifications, and for research investigations. When these materials are purchased under specifications, the necessity for systematic and careful sampling and the examination of every shipment cannot be overestimated, owing to considerable variations which are, at the present time, of common occurrence. The preparation of specifications for bituminous materials is a matter which should be handled by those familiar with their characteristics and value for different types of construction under different conditions, or else the specifications are apt to be not only worthless but so worded as to defeat the object of the party by whom they are prepared.