country each of us must make sure that he does not encourage unsafe practices by others.

It is believed that if the importance of attaching wire rope clips correctly is brought to the attention of highway engineers, the present situation will soon be remedied

THE BITUMINOUS SURFACE TREATMENT OF ROADS AND PAVEMENTS

W J Emmons

Director, Michigan State Highway Laboratory

Bituminous surface treatment is defined as the application of bitumen in fluid form to the surface of existing highways or pavements It may be employed on any of the standard types of construction, from earth roads through the several hard surface varieties The type of bituminous material, the amount of bituminous material, and the technique of treatment are dependent upon the nature of the surface to be maintained, and upon the results which are desired The elimination of dust, the waterproofing of the surface, and the prevention of disintegration through abrasion or displacement of weakly bonded surface materials are all objects of surface treatment In this report it is intended to review the objects of surface treatment on the several types of highway surfaces and to discuss briefly the requisite characteristics of the bituminous materials to give the desired results

I THE TREATMENT OF ROAD SURFACES COMPOSED PRINCIPALLY OF CLAY

Treatment of road surfaces of this type is undertaken for the purpose of (1) alleviating the dust nuisance, (2) waterproofing the road surface in order to render it less susceptible to softening during seasons of rain These objects are attained by the formation of a thin surface layer of bitumen coated soil particles

Ability to penetrate a fine grained, firmly packed, and often dusty soil is the most important quality to be possessed by a bituminous material for use on surfaces of this type One which dries or cures very slowly is also necessary as the bituminous surface layer must remain plastic in order not to break under traffic A high degree of adhesiveness is generally not a characteristic of materials possessing the foregoing properties and, in fact, is not a necessary property Successful treatment involves the formation of a surface layer which is mealy and plastic, rather than one which is tightly bound with highly adhesive bitumen

The state of Minnesota, during the last four years, has treated a considerable mileage of clay surface with oils which meet the above

definitions (1) Although the work in Minnesota was undertaken with a view of improving the soil as a subgrade, the highways were exposed to traffic without further protection than a thin surface course of gravel. Results have been highly promising, and these roads have suffered less severely from the action of water than did those which were not similarly protected

In Illinois, an elaborate investigation was conducted on a number of oils through the medium of service tests, and reported by Sperry (2) Conclusions referring to the quality of oil for use on earth roads were as follows·

"1 Semi-asphaltic and paraffin-base oils are superior to asphaltic-base oils for use on earth roads for the reason that they resist emulsification and retain their life much longer in contact with the soil and moisture

2 Reduced pressure tar is a satisfactory oil for earth roads

3 Binding qualities and adhesiveness are secondary in importance to the ability of the oil to resist emulsification and retain its life in contact with the soil This may not hold true in extremely dry climates

4 Cut-back or mat-forming oils which develop their asphalt content by the evaporation of their lighter constituents after their application are not well suited for earth roads

5 Non-volatile and homogeneous oils penetrate better and are more evenly and uniformly absorbed by the soil than blended products Blended oils tend to separate or fractionate when applied "

These references constitute the principal investigations of the application of bituminous materials to surfaces composed mainly of clay and the conclusions reached in the two states are in sufficiently close agreement to indicate that the principles established may be relied upon

The application of bituminous materials to roads of this class is accomplished by the usual method of pressure distribution Preliminary treatment involves the grading of the highway to the desired grade and contour, and the removal of loose and dusty material A bone dry condition is unnecessary, although the percentage of moisture which may be carried by the soil without seriously interfering with the satisfactory penetration of the bituminous material is not known Single applications of bituminous material in excess of one half gallon per square yard will generally result in the running off of a considerable proportion and consequently prove extravagant However, the rate of application depends upon the porosity of the soil and the characteristics of the bituminous material Minnesota usually employs a total treatment of about 75 gallon per square yard made in two approximately equal applications Dependent upon weather conditions, the second treatment is delayed one or more days, as complete absorption of the initial treatment is desired Although some classes of bituminous

materials may be applied cold, it is the practise in Minnesota to use oils which must be heated

The character of an oil suitable for treating clay roads precludes the possibility of picking up under traffic after it has been absorbed by the road surface Consequently a mineral cover is not absolutely essential, but it is felt that aggregate particles forced into the oil soaked surface will contribute to its stability, and is therefore preferable Minnesota practice employs a gravel application at the rate of approximately 80 pounds per square yard of surface This gravel is less than 1 inch in maximum size and, when obtained from local pits, may contain 30 or 60 per cent of coarse sand This results in a decided excess of covering which is maintained by blading in the same manner as a gravel surface maintained by the mulch method

The practice in clay surface oiling conforms to the above outline, which is based almost entirely upon service tests Additional research, correlating service results with laboratory behaviour should be undertaken The quality of oils which causes one to penetrate a dense clay and another to remain unabsorbed is not clearly understood The reaction of oils in combination with clay which sometimes results in emulsification in wet weather is likewise deserving of study In practice, while comparatively thin mats are stable under traffic, it is not known whether by successive treatments a bituminous layer several inches thick may be safely developed Should progressive thickening of the bituminous surface be feasible, an economical method of progressive development would be available for application to highways which otherwise would long remain unimproved

II THE TREATMENT OF SURFACES COMPOSED PRINCIPALLY OF SAND

Highway surfaces of this type vary from those which are composed almost entirely of sand, and which are virtually unbonded when dry, to the top-soil or sand-clay type which carry a sufficient amount of mineral binder to preserve them in a consolidated condition, regardless of ordinary climatic changes

The consolidation of loose sand by bituminous treatment has been a problem of local interest. Isolated instances, such as the one in Amargosa County, Nevada, described by McKesson and Frickstad (3), have been reported in which bituminous materials have been incorporated with the sand to form a surface layer of two to six inches, and have carried light to medium traffic satisfactorily An adhesive base bitumen is desirable for this use. Plasticity of the bituminous sand surface is essential, since the underlying material is likely to shift and ability of the surface course to conform to subsurface irregularities is necessary to prevent disintegration

In cases where bituminous treatment has been adopted for the

consolidation of sands, or in fact whenever combined with mineral matter by mixed-in-place methods, uniform distribution of the bituminous material throughout the mass is most necessary Long continued blading has been found to be the most effective means of accomplishing this end, and subsequent maintenance of the completed surface has been carried on by the same means

Considerable activity is evident in connection with the improvement of sand clay or top soil roads by means of surface treatments At least three distinct methods have been used and reported, as follows·

(a) The application of a fluid bitumen to the surface with the idea of developing a mat which is susceptible to further strengthening and thickening by succeeding treatments An example of this method is found on Long Island (4), where typical sand clay surfaces are treated without preparation except for shaping Successive applications with a covering of sand build up a thick mat which, becoming unstable, is scarified, mixed with the soil beneath, reshaped, and again treated In this manner bituminous surfaces six or more inches thick are developed

An asphaltic oil is used on these roads While this oil shows a considerable loss in the standard volatilization test, the residue resulting from the test is fluid With the evaporation of its lighter constituents such an oil becomes sticky but does not harden to the extent of brittleness

Experimental construction conducted jointly by the South Carolina State Highway Department and the Bureau of Public Roads included sections upon which were used fluid tars and slow curing oil in a manner similar to the Long Island method, although to swept surfaces (5) Thin mats were developed which were somewhat brittle or plastic dependent upon the characteristics of the bituminous material used In the experiments cited, the tars resulted in a rather fragile mat which was incapable of withstanding the considerable amount of steel-tired traffic to which it was subjected particularly in locations where the surface beneath was not well bonded The unfairness of attributing failure solely to the nature of the bituminous material is illustrated in this experiment Certain areas of the bituminous surface treated were covered with local top soil whereas the remainder were covered with a clean coarse sand The former acted very much as a blotter, and the lean mat which resulted proved far more fragile and susceptible to breaking up under traffic than did the sand covered work

A slow curing product which will be absorbed into the road surface, and which remains plastic, showed a promise of being a desirable treatment for well bonded soil roads under light traffic conditions The bituminous surface obtained by using such a material will deform rather than break when the support from beneath is lacking in uniformity

(b) The construction of a bituminous mat surface by the application

of a heavy residual bituminous product which will hold aggregate cover material ranging in maximum size from ½ to 1 inch The South Carolina experiments previously referred to included a number of sections constructed by this method The surface of the road was generally swept clean and primed by the application of a light bituminous product Within a day or two a residual tar or asphalt was applied hot, and immediately covered with crushed stone. Rolling completed the operation

This type of treatment builds a mat of about one inch thickness The priming coat of bitumen is designed to insure a bond between this mat and the underlying mineral surface Although satisfactory results were obtained without the priming coat its use is probably safer and the extra cost justified It was found that surface treatment of this nature should receive an additional application of bitumen before going through the winter season, and on sections where this was not given, subsequent maintenance costs were considerably increased A well bonded road surface is a prerequisite to the successful treatment of this type Looseness of the untreated road will result in local breaks in the subsequent treatment and unless the soil road is sufficiently strong in bond and in thickness to carry the traffic to which it will be subjected, the treatment by this method is not advisable

(c) The mixing-in-place of a fluid bitumen with the loosened soil surface to form a bituminous layer two or more inches in depth

In California (3), certain roads have given satisfactory service over a considerable number of years when constructed according to this method In this case a characteristically slow drying light residual California petroleum is used Although sold under the name of fuel oil, it is asphaltic in nature and develops about 65 per cent of residue of 80 penetration This type of construction appears to have been very successful when used in connection with surfaces comparable with sand clay roads

Experiments with mixed-in-place construction were included in the South Carolina experiments above referred to Both cold application coal tar and a rapid drying cut-back asphaltic oil were used In these experiments it was found very difficult to incorporate exactly the percentage of bituminous material required to properly bond the particles without producing an unstable mixture Moreover, the mixtures became hard and brittle as the volatile cut-back medium evaporated from the cut back oil It was finally decided in connection with these South Carolina experiments that the most promising procedure was to develop a very lean mixture of sand-clay and bitumen and to protect it from abrasive wear by the application of a surface treatment mat In this manner the body of the road was somewhat bonded with bitumen and instability guarded against

In this method of construction, experience has shown that a slow drying bituminous material possessing some adhesiveness is necessary. The mixed top should be plastic if a truly bituminous bound surface is to be attained Distribution of the bitumen throughout the soil layer must be uniform A local excess of bitumen will result in displacement of the mixture under traffic and a deficiency will permit failure through disintegration under traffic and climatic agencies The California work shows that successful construction may be obtained by the mixed-in-place method under certain conditions The South Carolina work shows that quick drying bitumens are not likely to be satisfactory and that under the conditions which prevailed in that location, at least, difficulties are encountered in securing the exact percentage of bitumen necessary to render the surface stable and at the same time self-healing and water proof The expedient of adopting a lean mixture using a bitumen which does not become brittle, and further protecting the surface by a rich seal coat is worthy of consideration.

III TREATMENT OF ROAD SURFACES COMPOSED OF GRAVEL

The surface treatment of gravel roads has been practiced for many years and many variations in procedure have been developed. A wide variety of bituminous materials have been used to meet definite conditions of the surfaces to be treated and the local conditions of traffic and climate The subject will be divided into two sections dependent upon the nature of the gravel surface to be improved, as follows:

(a) Well bonded gravel roads free from an excess of loose material on the surface The simplest and surest method of obtaining satisfactory results upon a surface of this nature is that of sweeping the road free from all dust and loose particles, applying the bituminous material and covering with coarse sand, pea gravel or chips. Maine has long successfully employed this method and the practice in that State has been described by Sargent (6) The bituminous material for this use may be one designed for cold or for hot application A slow or a rapid curing bitumen may be used It is characteristic of the former that somewhat greater penetration into the road surface will be obtained and of the latter that the unabsorbed bitumen will form a mat of greater thickness on the surface Naturally in the latter case, a greater proportion of the mineral cover will be held Adhesive hot application materials applied directly to the cleaned gravel surface have frequently been successfully used, and will hold mineral cover of larger maximum size than will the more fluid bitumens Unless the surface is practically free from dust and pockets of fine material, the hot application material should not be employed, as the bond with the gravel surface may not be sufficient to insure against slippage under traffic. The expedient of priming such a surface with a light bitumen and following with a

heavier one is a modification of the hot application method which is used to advantage.

(b) Gravel roads composed of loosely bonded material Bituminous treatment in this case has as its function not only protection of the surface but also the consolidation of an appreciable depth of a loose gravel. In California (3) this has been successfully accomplished by the mixed-in-place method, using the fuel oil residual grade obtained from California crude oils A thickness of loose material of 3 inches has been stabilized in that State. In other states, methods have been developed to surface mix the gravel with oils or tars The Wisconsin method (7) is an example of this type, and Minnesota has more recently developed a modification which has given excellent results in that State (1) Bitumens which gradually dry within three days are regarded as most desirable for this work The mat developed is $\frac{3}{4}$ inch or more in thickness, and where the support of the road is adequate, bituminous materials which yield a somewhat hard and non-plastic mat are satisfactorily used. If deformation of the road in wet weather conditions may be anticipated, brittle mats are likely to disintegrate rapidly under adverse conditions, and under these circumstances bitumen which yields a plastic, ductile, adhesive residue is to be preferred.

IV TREATMENT OF WATER-BOUND MACADAM SURFACES

The methods for use in the surface treatment of water-bound macadam roads are virtually those which have prevailed for a number of years. The essential features are the thorough cleaning of the rock surface, the application of bitumen, and the cover of mineral matter.

Both oils and tars are widely used for this purpose The most advanced thought indicates that the utmost care should be taken to choose a bituminous material which will penetrate into the closely bonded water-bound surface for the initial treatment, the surface mat being of minor consideration at this stage With this idea in mind, some authorities specify a very fluid grade of bitumen for the first treatment, and follow this within a few months, or possibly a year, depending upon local conditions, with a second treatment which will hold a heavier mineral cover Pennsylvania practice is illustrative of this tendency, and this State insists that the first treatment be made with a low viscosity tar which has the property of penetrating the surface Subsequent applications are made of either petroleum or tar products

The use of a priming coat as the initial step in the formation of a bituminous surface is felt to be excellent practice, as it guards against displacement under traffic of the mat which will be later developed

Hot surface treatments are popular with some engineers, but their success is dependent not only upon the character of the bitumen, but more particularly upon the thorough cleaning of the road before applica-

tion, and the amount of bituminous material which is applied. The development of thick carpets is dangerous unless a good bond is attained with the broken stone road, and unless traffic is light.

In some instances double applications of hot residual products have been made with an intervening application of coarse aggregate Such construction results in the formation of a surface closely comparable to those constructed by the penetration method, although soft bitumens have generally been used Where excessive bitumen has not been applied, and where the traffic is not too heavy, this method has proved successful

In general, the most satisfactory examples of surface treatments on water-bound macadam roads which have been maintained without reconstruction over a long period of years have been those formed by light treatments of oils or tars which lose their lighter constituents quickly and develop an adhesive residue Excessive applications are avoided and retreatments made only to replace material lost under traffic By avoiding the development of a thick mat, the stability of the surface is preserved and the broken stone at the same time is protected from those traffic forces which quickly disintegrate a water-bound macadam surface

V TREATMENT OF CONCRETE PAVEMENTS

Protection of concrete wearing surfaces by a method of bituminous surface treatment has been attempted in numerous instances During the year 1914 the experimental concrete pavement laid on Connecticut Avenue, Chevy Chase, Maryland, by the Bureau of Public Roads was in part treated with a number of bitumens (8) Various other trials of this method have been made but in many instances it has been felt that this method was likely to prove unsuccessful, due to the inability of bitumen to adhere permanently to the concrete surface The bituminous surfaces on the Connecticut Avenue experiment were permitted to wear without maintenance for approximately two years. At the end of that time a survey disclosed that much of the bituminous material had disappeared, but the fact that much still remained on the side of the pavement which was exposed to the lighter traffic indicated that under the proper conditions, properly timed retreatments would very likely maintain an unbroken surface mat. A number of materials were used in this experiment, both tars and asphalts, but the results were neither consistent nor conclusive On certain of the sections the concrete was primed with a light bitumen and in one case with an asphaltic emulsion previous to the application of the heavier hot application bitumens which formed the protective mat. It was not indicated that the priming coat resulted in longer life.

The City of Ann Arbor, Michigan, has long maintained surface

treatments on concrete pavements which were constructed fifteen or more years ago In this instance, light residual tar is employed and applications are made at intervals of not less than one year at the rate of about 0 25 gallons per square yard Gravel $\frac{3}{16}$ to $\frac{1}{2}$ inch in size is used as a cover.

The State of New York is at present employing bituminous maintenance on scaled pavements On roads which are subject to traffic not exceeding 3000 vehicles per day, light tars, which are found to have a desirable ability to penetrate into a slightly dusty surface, asphaltic cut-back or emulsion is used on shallow scaled areas and covered with coarse sand, gravel or stone chips Deeper depressions are similarly treated with residual bitumens Upon more heavily traveled roads, this State recommends a surface mat of about $\frac{3}{4}$ inch thickness formed by a $\frac{1}{2}$ gallon per square yard treatment of a heavy residual bitumen and a cover of aggregate, ranging in size from $\frac{1}{2}$ to $1\frac{1}{4}$ inch

Evidence gathered by this committee as well as that cited in 1926 by the Committee on Maintenance of this organization (9) shows that bituminous surface treatments can be maintained on concrete pavements Most certainly the bitumen must be adhesive to adhere to the concrete and to hold mineral cover It should also dry or harden quickly to avoid inconvenience to traffic

VI THE TREATMENT OF BRICK AND STONE BLOCK SURFACES

Treatments of block pavements are made for the purpose of smoothing irregular surfaces

Adhesive residual bitumens are generally used for such treatments, as these materials, applied hot, hold a heavy application of mineral cover, and can, moreover, be almost immediately opened to traffic without damage either to the surface or to the vehicle

Quick drying cut-back products may also be employed, although less mineral cover may be applied and in consequence a much thinner mat of less durability will result Some picking up under traffic may also be anticipated if opened immediately to traffic

Attempts to construct mats of a thickness greater than $\frac{3}{4}$ inch frequently result in wavy surfaces under heavy traffic It is better practice to patch depressions in advance and hold the mat to a maximum thickness of $\frac{1}{2}$ inch

VII THE TREATMENT OF BITUMINOUS PAVEMENT SURFACES

The renewal of the seal coat in bituminous macadam or bituminous concrete is necessary at intervals The bituminous treatment for this purpose should be just sufficient to coat the surface and hold a light mineral cover Two-tenths of a gallon per square yard of surface is generally ample. A slow curing bitumen is unsuitable for this use as

the cover material will be brushed from the pavement before the bitumen hardens and, in addition, the surface will be rendered dangerously slippery

The quick drying products, applied cold, as well as adhesive residual products are suitable and both have been successfully used

Specifications and test values

In this report an attempt has been made to describe current procedures in the field of bituminous surface treatment, to summarize important research, and to define in general terms the bituminous materials suited to various uses For most surface treatment purposes corresponding grades of oil and tar products are marketed The extreme diversity of controlling conditions of use and the lack of uniformity in bituminous specifications among both consumers and producers particularly as regards petroleum and asphaltic products, have rendered the inclusion of analyses or specifications inadvisable A consideration of the conditions surrounding the local problem should indicate to the engineer the essential characteristics of material suited to his purpose

It should be borne in mind that surface treatment is a maintenance provision and that service results are as much dependent upon the adequacy of the untreated road as upon the bituminous material employed After the treatment is applied the original road structure still supports the traffic and, except as its integrity is preserved by protection against the entrance of surface water and direct abrasion of traffic, the load carrying capacity is not materially affected by the thin bituminous surface.

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