DEPARTMENT OF MATERIALS AND CONSTRUCTION

Tests and Theories on Penetration Surfaces

JEROME P. KEARBY, *Senior Resident Engineer*
Texas Highway Department

THIS paper is devoted to a recommended practice in determining the amounts and types of asphalt and aggregate required in the construction of one-course asphalt surfacing treatment and seal coating. We have most nearly approached the desired results by using coarser grades of aggregate of nearly uniform size with a spread ratio just sufficient to slightly more than cover the surface one stone in depth and by limiting the asphalt to an amount sufficient to embed only a portion of the thickness of the loose mat of aggregate.

● THERE are a number of basic types of asphalt surfaces and pavements and numerous variations in materials and construction methods have been used in the construction of these different types. The selection of type, as well as the materials and construction methods, may therefore be governed by a number of local conditions, including: volume and weight of traffic, characteristics of available mineral aggregates and asphaltic materials, available construction equipment, and cost.

This paper deals with what is known to the Texas Highway Department as "asphalt surface treatments," which consist of the application of a thin layer of asphalt covered with crushed stone, washed gravel, or coarse sand. The asphalt is applied from mobile distributors through spray bars which apply the hot asphalt uniformly in the desired amounts. The aggregate is applied uniformly from spreader boxes attached to the rear of dump trucks.

While this procedure is called surface treatment by the Texas Highway Department, its most general use is the finished riding surface on compacted flexible bases composed of gravel, crushed stone, stabilized soil, or merely a selected material with low plasticity and limited shrinkage properties.

This type of road surfacing has been used satisfactorily on heavy-traffic primary highways, as well as low-traffic farm roads, the degree of success being largely dependent on the strength of the subgrade and flexible base rather than the asphalt treatment, itself.

The surface treatment serves as a waterproof cover, preventing the base from getting wet and soft during rains and from becoming dry, dusty and loose in dry weather.

THICKNESS OF TREATMENT

These surface treatments are usually very thin; in fact, most often less than 1 in. thick and frequently as little as ¼ in. thick. While the heavier surface treatments are desired and recommended, we have found that the lighter surface treatments have, in general, proven satisfactory where the subgrade and base materials were of high quality, of adequate thickness, thoroughly compacted, and well drained.

Due to oxidation and wear after several years and at several-year intervals, it is necessary to repeat the asphalt surface treatment in order to reseal and rejuvenate the original surface or to provide a nonskid surface. In the Texas Highway Department these repeated applications are known as "seal coats," and are applied similarly to the original surface treatment.

This subject of penetration surfaces has developed many controversial ideas, and it is not our desire to add to these, nor do we desire in any way to belittle or cast any reflection upon any ideas, as we realize that they all have their merits, and have been more or less satisfactorily used.

During the past several years, much time and thought has been devoted to the construction of satisfactory asphalt-treated surfaces. Much valuable information has been derived from experiments and studies, but heretofore we have known of no standard and reliable procedure by which the quantities of asphalt and aggregate may be predetermined with any degree of satisfaction. With this in mind, we have endeavored to devise a set of procedures which will reasonably assure economical asphaltic treated surfaces with the following characteristics: a smooth-riding, nonskid, waterproof surface of uniform texture and color which will minimize dust and flying rock particles during construction.

DETERMINING AMOUNT OF MATERIAL

This paper is devoted primarily to presenting a practical method of predetermining the amounts of asphalt and aggregate required in the construction of one-course asphalt surface treatments and seal coats. All too often the methods used in the past have been to apply the asphalt at a rate which worked good last summer and endeavor to incorporate the amount of aggregate which worked good last summer, even though the aggregate may be from a different source or from the same source and entirely different in physical characteristics. The results, as might be expected, are often unsatisfactory.

We feel that we are in need of a design procedure which has the advantages of simplicity and uniformity by which we may predetermine the quantity of an asphalt cement which, when a specific aggregate is applied and rolled in, will in turn be pressed up to that point which will embed the aggregate sufficiently to prevent displacement and yet will not be close enough to the top of the aggregate mat to permit tires of passing traffic to pick it up and spread it along the road. In the following we will outline those test methods by which this may be accomplished with a minimum dependence upon visual approximation and judgment. It must be remembered that computations alone cannot produce satisfactory results and that certain conditions require visual inspection and the use of judgment in the choice of quantities of asphalts and aggregates.

We have observed that in using the coarser grades of aggregate of nearly uniform size with just sufficient aggregate to slightly more than cover the surface one stone in depth and by limiting the asphalt to an amount sufficient to embed only a portion of the thickness of the loose mat of aggregate, we have most nearly approached the desired results.

In general, most specification requirements for gradations of aggregates are very broad, permitting coarse-graded aggregates, fine-graded aggregates, and aggregates graded fine to coarse, to be furnished within the limits of each grade. These aggregates, when carefully analyzed, vary considerably in particle sizes and shapes, as well as percent of voids.

The succeeding suggestions for asphalt surfacing and seal coating are recommended for use under what may be termed general and average conditions. It is realized, however, that no single standard procedure will cover satisfactorily all the variations in local conditions which may prevail for individual jobs.

The quantity of aggregate and asphalt required varies according to the character of the aggregate, being influenced by the unit weight, percent of voids, shape and size of the particles. Thus, as a rule, somewhat less weight of slag and certain gravels are required for a given amount of asphaltic material as compared with most grades of broken stone. The engineer should modify the amount according to local conditions. For surface treatments in general, it is better to err on the side of a slight deficiency of asphalt so as to avoid a fat, slick surface. Our first and last thought should be to avoid the hazard to traffic created by flying rock particles, and the danger to traffic created by fat, slick surfaces.

It is our opinion that the aggregate in an asphaltic surface treatment should be sufficiently embedded as to resist displacement but not so deeply embedded after compaction as to permit tires to reach and spread the asphalt.

QUANTITY OF AGGREGATE

The quantity of aggregate should be that amount which is required to form a blanket one stone in depth. That is to say, each aggregate particle covers a portion of the area. Therefore, the quantity of aggregate is definitely fixed and determined by its unit weight and the shape and size of aggregate particles. The quantity of asphalt, on the other hand, is variable and dependent upon the percentage of voids in the aggregate, the desired depth the aggregate is to be embedded in the asphalt, and to some extent, upon the type of surface or base on which the treatment is to be placed, as well as the hardness of the aggregate, and the type, kind, and amount of traffic.

The main factors involved in predetermining the amount of aggregate and asphalt required for satisfactory asphalt surface treatments are: (1) the quantity of a given aggregate required to cover 1 sq. yd. in area and the average thickness of the aggregate when placed so as to form a blanket one aggregate in depth (which we term the "effective mat thickness") and (2) the amount of asphalt per square yard of surface which will be required to embed a desired portion of the effective mat thickness of the aggregate.

The aggregate should be carefully analyzed to determine its unit weight, specific gravity, percent of voids, and screen analysis. From the screen analysis the average particle size and effective mat thickness of the aggregate is determined by multiplying each individual screen size by its individual percentage and then obtaining the sum of the products. The result is in fractions of an inch and when divided into 36 in. gives the number of square yards of area which may be covered by one cubic yard of aggregate and is termed "spread ratio." This method of determining average aggregate particle sizes, theoretical mat thickness and spread ratio for a cover of one stone average thickness, can be satisfactorily used if flat and elongated particles are not present.

TEST-BOARD METHOD

For most aggregates, and especially for aggregates containing flat and elongated particles, the square-yard-test-board method should be used to determine the effective mat thickness and spread ratio, the procedure being as follows:

Obtain a 1-sq.-yd. test board. Place a sufficient quantity of the aggregate on the board as necessary to obtain a full coverage one stone in depth. Weigh the aggregate required for the one-stone-depth coverage. Then, the pounds per cubic yard divided by the pounds per square yard equals the spread ratio in square yards per cubic yard. The effective mat thickness is obtained by dividing 36 in. by the number of square yards covered per cubic yard.

The quantity of asphalt required is dependent upon the percent the average aggregate mat thickness is to be embedded in asphalt and the percent of voids in the aggregate. The desired percentage embedded times the average mat thickness equals the embedded depth. One square yard, or 1,296 in. times the desired embedded depth, times the percent of voids in aggregate, equals volume of asphalt required per square yard based on the hard grades of oil asphalts containing approximately 99 percent bitumen.

This calculation is not precise in that the percent of voids in the embedded portion of the aggregate mat, when first placed, is not necessarily the same as in the aggregate sample. The percent of voids in the embedded portion of the aggregate mat can be determined by laboratory tests. However, we have observed that in using the percent of voids in the aggregate sample as a factor in the design procedure, satisfactory results have been consistently obtained. If liquid asphalts containing volatiles or emulsion asphalts containing water are used, then the quantity should be increased proportionately to their bitumen content, except for "seal coats" being applied on existing, slick asphalt surfaces, in which case, if liquid asphalts containing volatiles are used, the quantity of liquid asphalt need not be increased, because the volatiles tend to soften the existing asphalt surface, permitting partial embedment of the aggregate into the existing surface and resulting in reduced effective mat thickness of the aggregate applied.

It has been our experience that a considerable excess of aggregate is often more detrimental than a slight shortage, in that with an excess of aggregate the amount of fines applied is also increased. The excess of fines tends to go to the bottom and become embedded in the asphalt or blot the surface of the asphalt, thereby preventing the embedding of the coarse-aggregate particles and allowing a large percent of the coarser particles to be subject to whip-off, leaving a fat or flooded condition. It is our opinion that the material passing the 10-mesh sieve acts as a filler, thereby raising the level of the asphalt appreciably and cannot be counted on as cover material to furnish any riding surface.

ASPHALT-APPLICATION-RATE CHART

Figure 1 is an asphalt-application-rate chart, constructed from mechanical computations, from which the gallons of bitumen per square yard can be obtained after having determined the average aggregate mat thickness and the percent of voids in the aggregate and having selected the desired embedded depth. Along the vertical and horizontal axes we have indicated the average aggregate mat thickness for each ⅛-in. thickness up to 1 in.; also, the percent of aggregate mat embedded for each 5 percent from 20 to 50 percent.

On the inner circular lines connecting corresponding average aggregate mat thicknesses, we have indicated the computed gallons of asphalt per square yard for each 0.01 gallon. On the outer circular lines connecting corresponding percent of aggregate mat embedded, we have indicated the various percent of voids from 10 to 60 percent.

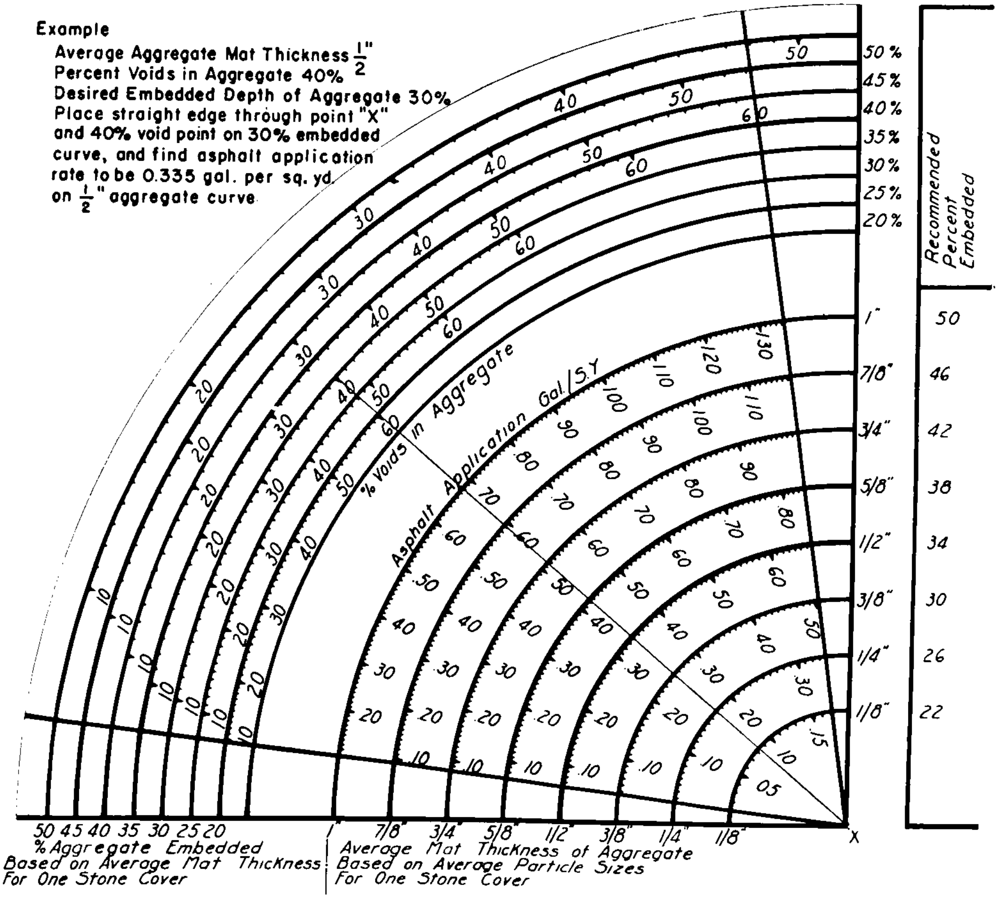

Figure 1.

To determine gallons of bitumen required per square yard, follow the desired percent embedded curve to point indicating the percent of voids in the aggregate; connect this point with apex point X, using straight edge or string; follow along the line so established to curve representing the average mat thickness and read directly gallons of bitumen required per square yard. Note: If liquid asphalts or emulsions are to be used, the rate of application should be increased proportionately to bitumen content. Your attention is invited to the broad variation in bitumen required, dependent upon the percent of voids which may be as low as 30 percent or as high as 50 percent.

It must be remembered that when applying asphalt surface treatments on existing fat asphalt surfaces and on loosely bonded or soft base courses, and especially when liquid asphalts containing volatiles are used, a portion of the aggregate during rolling will penetrate below the film of freshly applied asphalt, thereby reducing the effective mat thickness of the cover material. Also, when the softer grades of aggregate are used, some of the larger sizes will be crushed by rolling, thereby reducing the effective mat thickness as well as the voids.

Under conditions as mentioned above, it is recommended that the percent of embedment used in the design be reduced, dependent upon the existing conditions. We know of no way to actually determine to what extent aggregate may penetrate through the freshly applied asphalt and into a loosely bonded soft base or into existing fat, soft asphalt surfaces, nor to what extent the softer grades of aggregate will be crushed during rolling; however, these factors can be estimated to some valuable degree by placing one layer of the selected cover aggregate on the base or old asphalt surface which is to receive treatment and observing its condition after thorough rolling with the type of rollers to be used on the job.

When applying asphalt surface treatments to existing hard-paved surfaces or tightly bonded, hard base courses, it is recommended that the percentage embedded be increased if hard aggregates are used and reduced if aggregates are soft and break up under rollers.

Some allowances should be made, depending on the amount and type of traffic. For highways carrying high traffic counts and heavy vehicles, the percentage embedded should be reduced and larger aggregates used. For highways carrying light traffic counts and light vehicles, the percentage embedded should be increased and medium size aggregates may be used.

The percent of aggregate mat embedded in asphalt as recommended herein may appear somewhat light; however, this procedure is based on loose aggregate mats, which under traffic will change considerably in that aggregate particles will be rearranged and further consolidation will take place, thereby reducing the aggregate mat thickness and percent of voids and increasing the percent of aggregate embedded. Your attention is again invited to the possible and probable variation in average size and spread ratio within some specification limits, which is still greater when flat and elongated particles are present.

TABLE 1
RECOMMENDED GRADING OF AGGREGATES FOR ASPHALT SURFACE TREATMENTS

Grade I	Retained on 1⅛″ Retained on 1″ Retained on ⅞″	Screen Screen Screen	0% 40–60% 95–100%
Grade II	Retained on 1″ Retained on ⅞″ Retained on ¾″	Screen Screen Screen	0% 40–60% 95–100%
Grade III	Retained on ⅞″ Retained on ¾″ Retained on ⅝″	Screen Screen Screen	0% 40–60% 95–100%
Grade IV	Retained on ¾″ Retained on ⅝″ Retained on ½″	Screen Screen Screen	0% 40–60% 95–100%
Grade V	Retained on ⅝″ Retained on ½″ Retained on ⅜″	Screen Screen Screen	0% 40–60% 95–100%
Grade VI	Retained on ½″ Retained on ⅜″ Retained on ¼″	Screen Screen Screen	0% 40–60% 95–100%
Grade VII	Retained on ⅜″ Retained on ¼″ Retained on #10	Screen Screen Mesh	0% 40–60% 95–100%
Grade VIII	Retained on ¼″ Retained on #10 Retained on #20	Screen Mesh Mesh	0% 40–60% 95–100%

AVERAGE SPREAD RATIO FOR SINGLE APPLICATIONS

No. 1	1:36
No. 2	1:41
No. 3	1:48
No. 4	1:58
No. 5	1:72
No. 6	1:96
No. 7	1:144
No. 8	1:288

GAP GRADING

Your attention is also invited to the probable gap grading allowed within some specifications with a very small percent of the top aggregate sizes and a large percent of the bottom aggregate sizes. These gap-graded aggregates frequently result in unsatisfactory asphalt surface treatments because:

If the quantity of asphalt used is sufficient to adequately embed and retain the average particle size, it is not sufficient to adequately embed and retain the top aggregate size. If the quantity of asphalt used is sufficient to adequately embed and retain the top aggregate size, the average particle size will be flooded with asphalt, resulting in an undesirable fat, slick surface.

The small percentage of oversize particles of aggregate permitted by some specifications are usually the flying stones that we hear so much about as being hazardous and damaging to traffic. The excess percentage of undersize particles of aggregates permitted by some specifications are often times so fine as to blot the asphalt film and prevent the larger aggregates from becoming embedded in the asphalt. In many cases, specifications allow gap-graded aggregates which are undesirable and also allow aggregates graded uniformly from fine to coarse, with maximum density and minimum voids desirable for certain asphalt mixes but very undesirable for penetration-asphalt surface treatments.

Table 1 is a recommended grading of aggregates for asphalt surface treatments.

The gradation of aggregates recommended will provide aggregates of nearly uniform size which can be uniformly applied and spread without oversize particles, which most frequently are either crushed during rolling or fail to become embedded in the asphalt and remain loose on the surface until broomed off or whipped off by traffic.

An aggregate of approximately uniform size with a maximum of voids is most desirable for penetration-asphalt surface treatments in order that a maximum amount of asphalt binder may be used without the aggregate becoming sufficiently embedded to result in a slick, bleeding surface. Also, the uniform size aggregates usually develop better interlocking qualities and provide lateral support to adjacent particles, thereby preventing displacement from traction and friction of high-speed traffic.

DEFINITION OF FLAT AND ELONGATED PARTICLES

The specifications should limit the amount of flat and elongated particles in the aggregate and define what shall be considered flat and elongated particles. We are of the opinion that flat and elongated particles combined should not exceed 10 percent of any aggregate gradation requirement. The following are suggested definitions for flat and elongated particles:

Flat particles are those particles with thickness of less than half the average width of the particle.

Elongated particles are those particles with length greater than twice the other minimum dimension.

To obtain best results under the methods described herein, the application temperatures of hard asphalts should be controlled within certain limits, depending on the viscosity of the asphalt. Asphalt should not be applied at a greater temperature than necessary, because the process of spraying asphalt at excess temperature reduces its penetration and ductility factors and frequently results in gravity flow of the applied asphalt on inclined surfaces.

The viscosity of asphalt varies greatly with changes in temperature, and the viscosities of various asphalts vary greatly at the same temperature. We have observed that best results can be obtained by heating the asphalts to such temperatures as to produce viscosities within a range of 40 to 60 with a possible optimum of 50.

A properly designed surface treatment will provide satisfactory results only if good construction methods are used. Good construction methods are so varied that it is appropriate only to suggest that the temperature of the air, aggregate, and base or surface, as well as the general weather and surface conditions, should be considered as controlling factors in determining suitable conditions for applying asphalt surface treatments and that thorough rolling with both flat-wheel and pneumatic rollers are virtually essential.

In conclusion, we are of the opinion that there should be closer control on gradation of aggregates and temperatures and on rates of application of asphalts and aggregates, and as in the case of asphaltic concrete, there should be some uniformity in design methods for asphalt surface treatments.

We do not presume that the design and test procedures and application methods presented herein are the final answer; however, we do hope that some of the suggestions advanced in this paper will improve our work and assist in arriving at the final answer.

We are indebted to various engineers too numerous to mention, for their outstanding work in experiments, tests, theories, and papers on this subject which have developed a background for our tests and theories.