POROUS SAND-ASPHALT MIXTURES

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Densely graded sand asphalts are relatively similar to conventional, bituminous concretes. Porous sand asphalts possess the same attributes as other porous, bituminous mixtures. Surely, sand-asphalt mixtures can be designed to be as porous as the so-called open-graded plant-mix seals. Particle shape and texture otherwise define skid resistance. Stability is an ensurance against scaling. Stability is ensured by maximum use of filler-bitumen ratio and the stiffness of asphalt cement.

•OTHERS seem to have forsaken sand asphalts in their search for skid-resistant pavement surfaces. But, the basic principles of the relativity of particle size and packing apply to sand sizes as they apply to pebble sizes. It is still possible to grade sands or silts to obtain a desired porosity. One merely shortens the gradation. Suppose, for instance, that a relatively short-graded sand with sufficient asphalt in it to prevent bulking compacts to 33 percent voids in mineral aggregate (VMA). Suppose, also, that 15 percent voids in the final mixture is desired. For a trial mixture, one might use 13 percent asphalt cement and 5 percent mineral filler (both by volume). For 2.64 specific gravity sand, this would yield about 6.5 percent asphalt by weight. The proportions of asphalt to filler may be adjusted to obtain maximum stability. Stability is necessary to prevent scaling and stripping.

Sands abound in many localities throughout the country. Not all sands are skid resistant. Shape and texture of particles are important attributes. Shape is discernible macroscopically and microscopically. The Goldbeck (1) bulking test is an empirical measure of order, or, conversely, a measure of disorder of shape. Perhaps the most unique feature of sand mixtures, one that has not yet been fully explored and developed, is the strong capillarity and wicking forces that may be achieved and made useful. Whereas drainage of larger, porous mixtures must depend on gravity flow, porous sand mixtures definitely blot and wick and may be designed, hopefully, to siphon.

The objectives are

1. To clear standing water from the pavement as quickly as possible,
2. To minimize hydroplaning, and
3. To avoid polished or polishing aggregate particles that can be lubricated by residual films of water.

Field tests are the final proof of success; however, one should retain an intuitive and scientific skepticism toward standard methods of test such as those now used to measure skid resistance.

RESEARCH AND DEVELOPMENT

From the early 1900s, Kentucky rock asphalt was much admired and respected for its skid resistance qualities. It was basically a porous sand asphalt. Its VMA ranged between 28 and 35 percent. Total voids ranged between 12 and 16 percent. It had an unforgivable weakness—it often scaled or delaminated. The mixture had very low stability when it was fresh. However, a study in 1955 showed an average life expectancy of 17.29 years (2).

Publication of this paper sponsored by Committee on Characteristics of Aggregates and Fillers for Bituminous Construction.

Elsewhere, sand asphalts or sheet asphalts were used as low-cost surfaces in areas in which sands were abundant. Pavement structures consisted of 1 or more courses of sand-asphalt or macadam base and perhaps 2 in. of sand (sheet) surface. Richardson apparently sought angular, sharp, silica sands as early as 1896 (3). Nicholson (4) published photomicrographs of prominent sands in 1926. A dilemma that still persists to some degree was expressed by Gage (5) in 1926, as follows:

> A natural rock asphalt mixture seldom contains much over seven percent of asphalt, yet we are all familiar with what would happen to a sheet asphalt mixture that only contains eight percent of asphalt. I do not think there is much doubt about the durability of some rock asphalt mixtures that do not contain much over seven percent of bitumen yet there is a grave doubt about the durability of the average sheet asphalt pavement that does not contain more than ten percent of bitumen. The stability of a sheet asphalt mixture containing eight and one-half or nine percent of bitumen may be greater than one containing eleven percent, yet the durability of one will certainly exceed that of the other.

Gage (5) apparently was recognizing not only the need for adequate stability but also the prerequisite need for coating thickness. A dense sand asphalt having 10 percent asphalt and a unit weight of 136.67 lb contains 1.58 times more asphalt per cubic foot than an open-graded mixture having 7.5 percent asphalt and a unit weight of 115.68 lb. The percentages by weight of aggregate would be 11.11 and 8.11, respectively. The ratio of the aggregate weights is 1.15:1. Surely, the ratio of the specific surface areas would be greater but not 1.58 times greater. It appears that there has been a tendency in the past to overlook rock asphalts' and other sand mixtures' due portion of asphalt or asphalt and filler. The filler-bitumen ratio appears to have been neglected, and stabilities have not been maximized (6). Scaling and stripping have resulted. Stabilities increase with increasing angularity and texture of the sand, increasing stiffness of asphalt, and increasing the filler-bitumen ratio to optimum. Antistripping agents provide precautionary ensurances against loss of stability in water.

The first generation of sand asphalts in Kentucky were designed to be very dense and stable. They did not scale, but they were not exceptionally skid resistant, and the shape of the sand was not controlled. It seemed necessary to prove that they could be designed to endure and to be as reliable in all respects as high-quality bituminous concrete.

Open-graded sand asphalts compounded to simulate Kentucky rock asphalt were first subjected to road trials in 1968 (7). Sand was selected visually and, after comparison, was judged to be similar but not quite equal to Kentucky rock asphalt sand. Without filler material, the surfaces scaled; with filler material, they did not. About 2 percent filler increased the stabilities from 40 to 80. Marshall stabilities in the range of 500 to 1,200 are thought to be necessary to withstand very high volumes of traffic. A simulated Kentucky rock asphalt has now equaled and slightly exceeded the Kentucky rock asphalt in skid resistance.

A crushed quartz conglomerate sand in a densely graded sand asphalt constructed in 1972 and 1973 compares favorably in skid resistance with a crushed quartz conglomerate in an open-graded plant-mix seal constructed in 1973 on an abutting section of the same road.

It is apparent that the shape and texture qualities sought in sands for sand asphalts are opposite to those sought for portland cement concrete and mortar sands. River sands, glacial sands, especially glacial outwash sands, and beach and blow sands tend to be rounded, frosted, and polished. Many sandstones and conglomerates yield sharp, angular sands. Crushed, manufactured, noncarbonate sands, altogether or blended with qualifying natural sand fractions, may provide new opportunities to use local resources and indigenous material to achieve skid-resistant pavement surfaces. Controlled wear and attrition are essential. The surface, therefore, becomes renewable.

Scaling, shown in Figure 1, is attributed to a deficiency in the design of the mixture—instability. Usually, such mixtures are deficient in asphalt or filler or both. Failures are accompanied by stripping of asphalt from the sand particles. Coatings are thin, and asphalt menisci are not well formed at the interparticle contacts. Persisting water or continual wetness in conjunction with loading accelerates scaling (8). Hard asphalts improve stability, minimize sponginess, and are more resistant to stripping. Anti-stripping agents may be needed with some aggregates. Durable Kentucky rock asphalt surfaces contained asphalt binders (after 15 years in service) having penetrations of about 15. No sand asphalt or rock asphalt having Marshall stabilities of as much as 400 has scaled.

TECHNOLOGY

Sand is defined as aggregate passing the No. 4 or No. 8 sieve. Historically, there have been 2 generic types of sand-asphalt surfacing mixtures: sand asphalts and sand sheet asphalts. Sand asphalts generally have been long-graded sands containing 4 to 14 percent passing the No. 200 sieve and 7 to 11 percent asphalt. Sheet asphalts generally have been finer, containing as much as 98 percent passing the No. 16 sieve, 8 to 16 percent passing the No. 100 sieve, and 7.5 to 12 percent asphalt. The latter is merely a fine sand mixture. A purposeful effort to open-grade and sand mixtures began in 1968 (7).

Aggregate Shape

A cubic packing of uniform spheres, regardless of size, contains 47.64 percent voids (9, 10). Rhombohedral or dense packing contains 25.95 percent voids. Although the isolation of a standard sieve series size of material provides a mixture of sizes in which the smallest particles are half the diameter of the largest, there is a high probability that a random arrangement and distribution of spherical particles in the size range will yield about 41 percent voids. Goldbeck (1) suggested a test in which excess bulking was to be avoided to ensure good concrete-making qualities of fine aggregates. Tests on concrete have indicated an upper limit of about 47 percent. Kentucky has used this type of requirement in its specification for crushed limestone fine aggregate for concrete for several years. Clearly, a size fraction yielding 50 percent or more voids indicates greater disorder in shape, texture, or cohesion.

Test Procedure

Particle shape and texture of each sand shall be controlled so that when it is subjected to the dry bulking test the volume of voids shall be 50 percent or greater. The dry bulking test shall be used as a source control test and thereafter shall be conducted as often as deemed necessary by the engineer. The following describes the test apparatus (Fig. 2).

1. The balance shall have a capacity of 1 500 g and a sensitivity of 0.1 g.
2. The pans for drying samples shall have at least a 1 500-g capacity.
3. The rigid, cylindrical cup shall have an inside diameter of $2\frac{7}{8}$ in. and a height of $5\frac{1}{2}$ in.
4. There shall be a truncated, hollow, metal cone having an overall height of 4 in. and an inside diameter of $5\frac{1}{2}$ in. for the large opening and 1 in. for the small opening.
5. No. 4, No. 8, No. 16, No. 30, and No. 50 size sieves are required.
6. A typical steel straightedge 1 in. by 6 in. by $\frac{1}{16}$ in. is required.

The sample of aggregate shall be washed thoroughly, dried to constant weight at 105 to 110 C, and separated into the following 4 sizes:

Passing	Retained
No. 4	No. 8
No. 8	No. 16
No. 16	No. 30
No. 30	No. 50

Approximately 1 500 g of each of the above sizes shall be required for the tests.

The test shall be conducted on only the specified size fractions having 5 percent or

Figure 1. Early scaling of sand asphalt having low stability and insufficient asphalt.

Figure 2. Test apparatus.

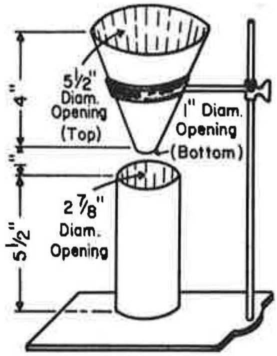


Figure 3. Bulking test for control of aggregate shape.

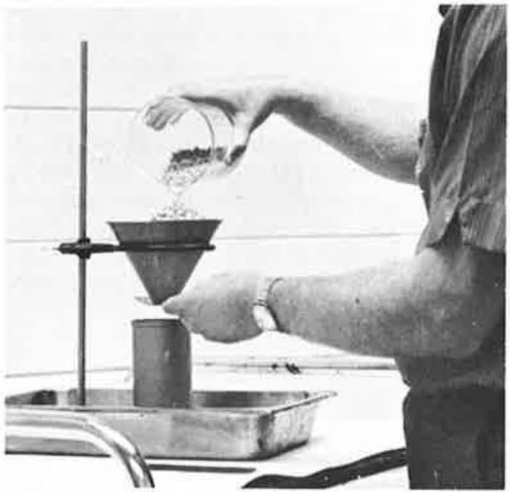
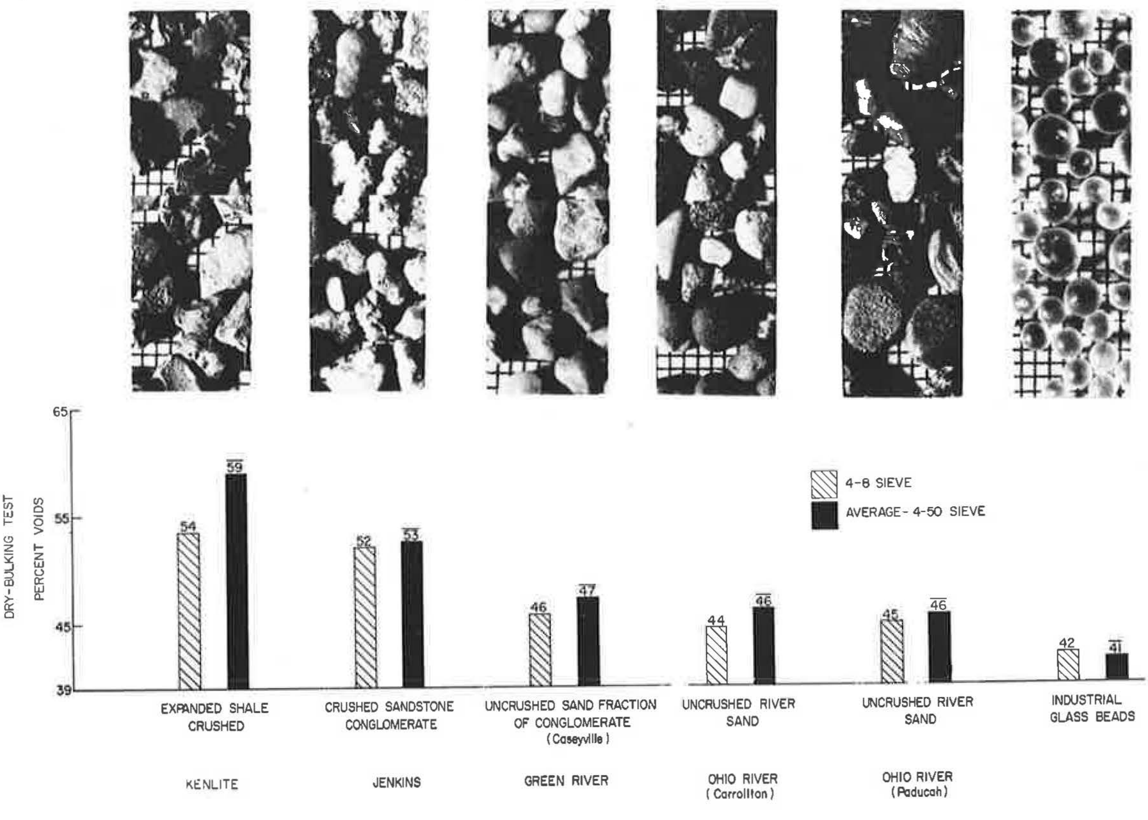


Figure 4. Bulking value of sands associated visually with particle shape, No. 4 sieve size.



more of the aggregate by weight contained in the given specified size fraction.

A size of the aggregate shall be poured into the funnel while a stiff piece of metal is held against the bottom opening. The funnel shall be filled until the material is heaped between 1 and 2 in. above its top level; care shall be taken not to overflow the funnel or to spill material into the cylinder below. The piece of metal used to close the bottom opening of the funnel shall be quickly withdrawn in a horizontal movement and the material permitted to flow freely into the cylinder until it overflows. Then, the flow of the material onto the filled cylinder shall be cut off, and any of the material remaining in the funnel shall be allowed to flow into a pan.

The material in the cylinder then shall be carefully struck off even with the top of the cylinder with the straightedge. This is accomplished by holding the straightedge in both hands, edge down; starting at one side, strike off the material above the top of the cylinder. The straightedge is then placed along a diameter of the cylinder and the material struck off again. This is then repeated in the opposite direction. Extreme care shall be taken during the striking-off operation to avoid any downward pressure on the aggregate or any jarring of the cylinder.

After carefully removing any material that may be adhering to the outside of the cylinder, the weight of the contents shall be determined to the nearest 0.1 g.

The aggregate in the cylinder then shall be recombined with the excess of the same size from the pan, thoroughly mixed, and 2 additional determinations made. An average of 3 determinations having a maximum variation of 4 g shall constitute a test.

The percent of voids in each size shall be determined by the following formula:

$$\text{Percent voids} = 100\left(1 - \frac{W}{VG}\right)$$

where

W = average weight of material in the cylinder,
V = volume of cylinder in cubic centimeters, and
G = bulk specific gravity (oven dry) of the aggregate as determined by the applicable portions of ASTM C 127.

The arithmetical average of the voids percentages so determined for the tested size, the sum of the percentages divided by the number of sizes tested, shall be reported. Figure 3 shows the test being performed.

Figures 4 through 7 illustrate, by association, the relationship between the bulking value and particle shape (11). The test is subject to some error when the aggregate is highly vesicular. Errors arise from inherent inability to determine the true, oven-dry, bulk specific gravity.

The bulk specific gravity of slag larger than the No. 4 sieve may be about 2.30; that of fine slag sand passing the No. 30 or No. 50 sieve may exceed 3.00. Expanded shale fines may range from 2.59 to 2.84. Quartz grains approach 2.64. All approach zero percent absorption as the size diminishes. The specific gravity of powdered material is equivalent to that of a voidless mass.

Porosity and Capillarity

A relatively dense sand-asphalt gradation divided at the No. 30 sieve will provide a coarse and a fine sand, each of which will yield about twice the VMA in asphalt mixtures as the original sand. The coarser fraction would not contain filler; it would have to be added. Such sorting might be accomplished in a wet classifier. All filler could be removed and proportioned back into each of the sands at the hot-mix plant. The 2 mixtures would be very much alike in terms of total voids (porosity) but would have very different pore sizes. Capillary rise and wicking would be greater in the finer mixture if the voids remained open and if the internal surfaces were wettable. Both the coarse and fine mixtures would exhibit wicking capabilities. Wicking is merely capillary forces at work in a porous medium.

Capillary rise, siphoning, and wicking are illustrated in Figure 8. Height, H, must

Figure 5. Bulking value of sands associated visually with particle shape, No. 8 to No. 16 sieve sizes.

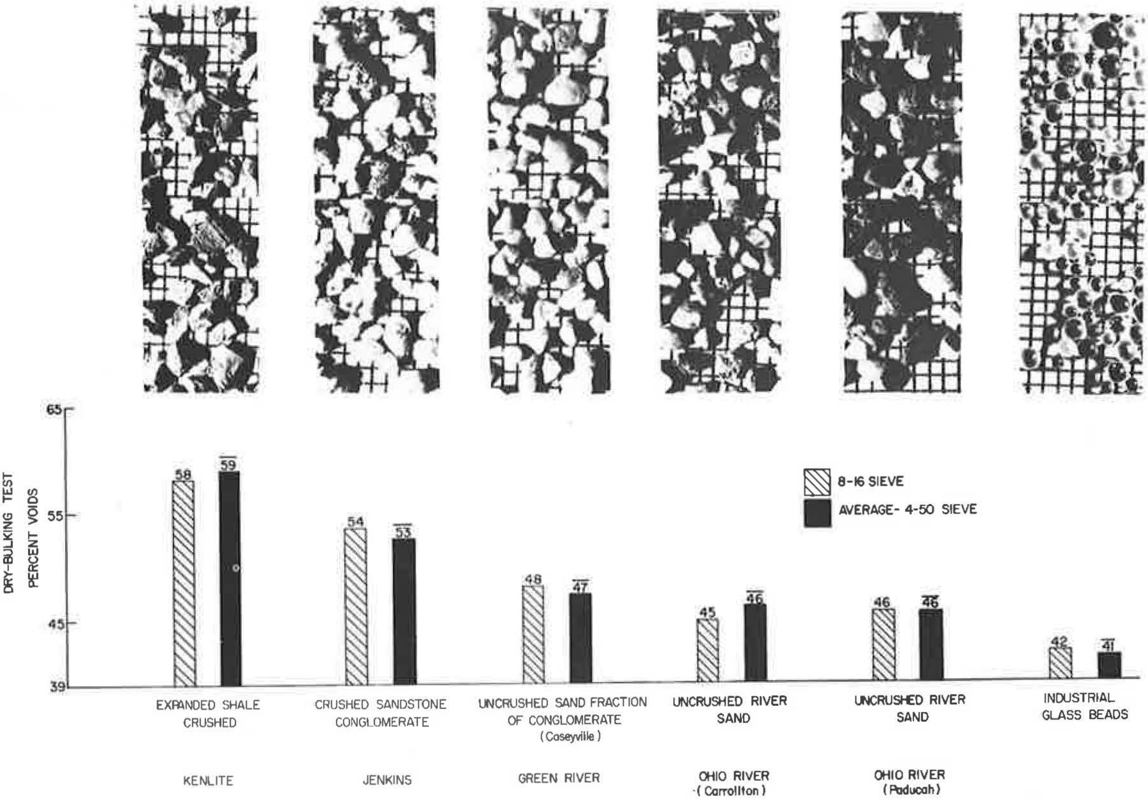


Figure 6. Bulking value of sands associated visually with particle shape, No. 16 to No. 30 sieve sizes.

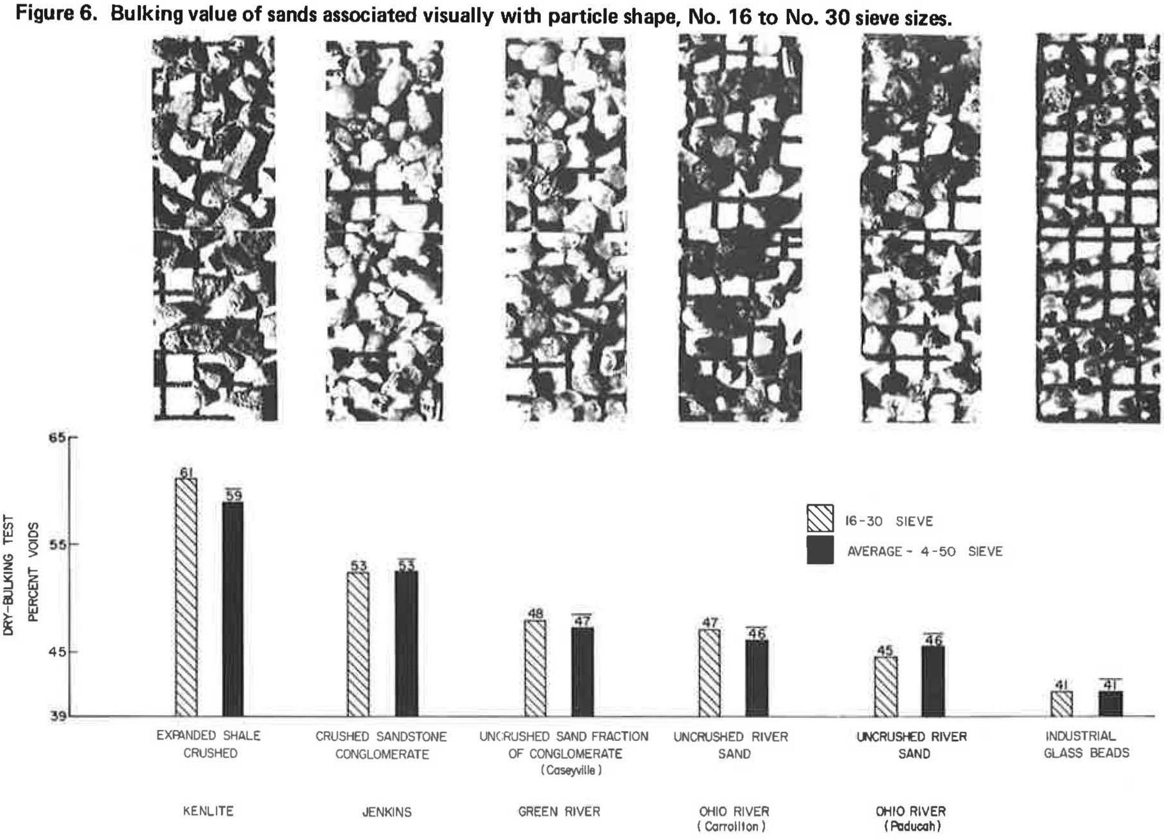


Figure 7. Bulking value of sands associated visually with particle shape, No. 30 to No. 50 sieve sizes.

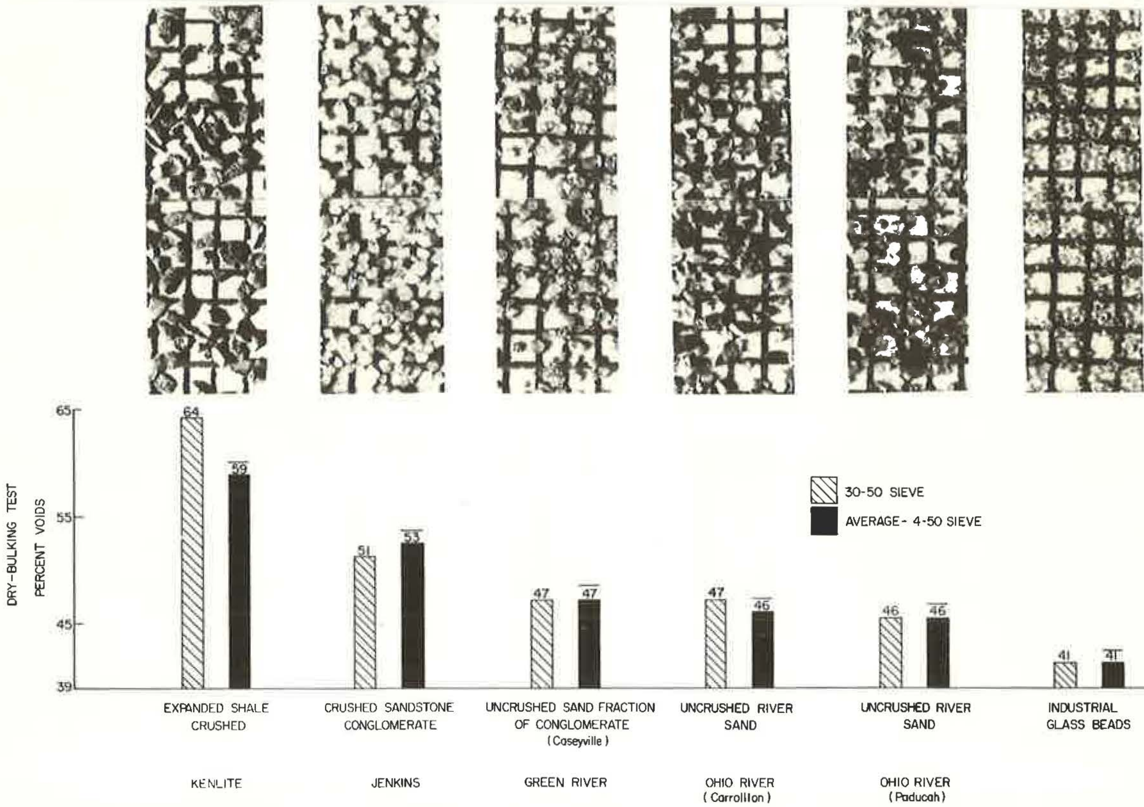
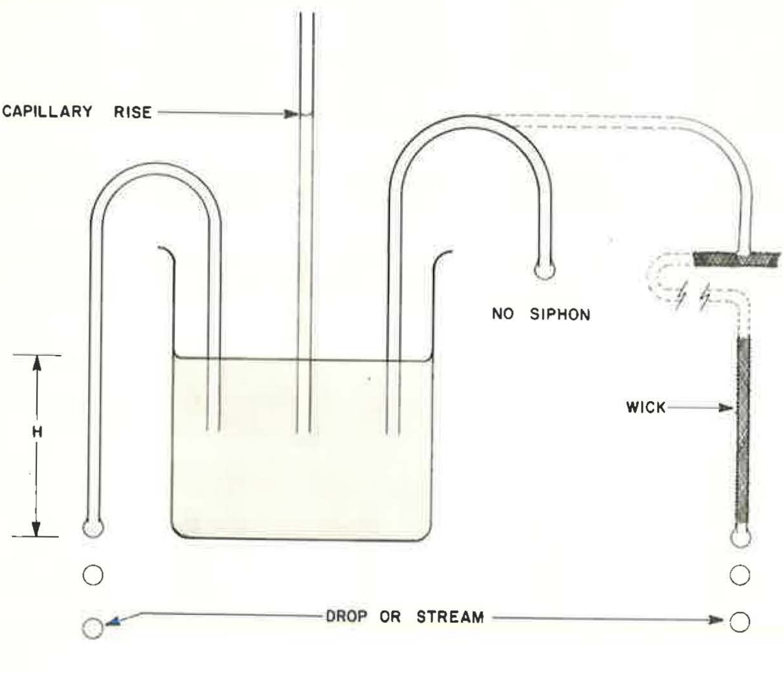


Figure 8. Capillary rise, siphoning, and wicking.



be sufficient to overcome the tensions holding the drop at the tip of the tube before efflux will occur. A wick may substitute for or extend a capillary tube, as shown.

Suppose the capillary rise is 1 cm in a surface course that is 2 cm thick; if the surface course were inundated by rain surface flow and some internal flow would carry the excess water to a lower elevation, the free-water surface would subside into the surface course; ordinary gravity drainage would cease at some point; and shallow basins would siphon (by capillary action) into lower basins and emerge laterally or surface at low points. Water that could form concave surfaces (menisci), because it has shorter radii than the pores causing capillary rise, would not drain; the hydrostatic law does not apply. As drying progresses the menisci recede, but blotting capacity remains high; additional water cast onto the surface is absorbed readily.

Clogging of Pores

Soil and road scum intrusions affect the porosity and surface texture of various types of bituminous surfaces. Dust tends to adhere to fresh asphalt until the asphalt loses its tack. Interior surfaces also retain dust; this mineralizing process improves wettability with respect to water and gives rise to capillary action. Permanent clogging may occur, but the pumping action induced by passing tires during rainy periods tends to flush and clear pores in the wheel paths.

Figure 9 shows a dense sand-asphalt surface outside the wheel paths that is clogged and not readily wettable. The view on the right shows the same drop of water after the addition of a wetting agent. The surface wetted, but there was no in-rush or blotting. In contrast, Figure 10 shows a drying porous sand asphalt (Kentucky rock asphalt) that has been fully wetted and flushed clean in the wheel paths. Blotting occurs readily. Traffic assists the wetting process if the surface is somewhat hydrophobic at first; it also hastens desaturation.

Tack Coat

Porous sand asphalts have a high blotting capacity toward asphalt used in the tack coat. An abundant tack application seems necessary to prevent delamination and to seal the underlying pavement. It is usually prudent to subtract an equivalent amount of asphalt from design asphalt content of the mixture. This adjustment becomes very significant when the sand surface course is very thin.

Particle Orientation and Surface Texture

Particles having 1 or more flat sides tend to be positioned in the surface during compaction so that they present a flat side rather than an acute angle or cutting edge toward the tire. In this position, the edges, if they remain sharp, contribute to tractive resistance. The microtexture of the flat surface may be lost through wear and polishing. Certainly, microtexture is obscured by asphalt when the surface course is new. Skid resistance should improve rapidly for a brief time and then diminish gradually to a more or less constant value. Attrition or loss of particles from an open-graded, plant-mix seal would give an impression of raveling; attrition from a sand surface would be desirable if it occurs uniformly and at a rate commensurate with the life expectancy of surface course. Indeed, a steady wearing away ensures against eventual polishing of sand grains at the surface. Finer sands appear to be more favorable from this point of view than coarse sands. Admittance of finer sands also permits a higher size-reduction ratio and provides greater angularity when sharp sands are manufactured by crushing coarse sands or pea gravel. No. 4 to No. 8 sizes do not appear to be essential to the performance of sand mixtures.

Orientation of particles of fine, crushed quartz sand that are oiled and compressed lightly against a flat surface is shown in Figure 11.

SUMMARY

Skid Resistance

Dense sand asphalts containing blends of crushed limestone sands and natural sands

Figure 9. Quarter-inch-diameter bead of water (left) on dense, clogged sand-asphalt surface not readily wet; wetting agent induces wetting (right) without blotting.

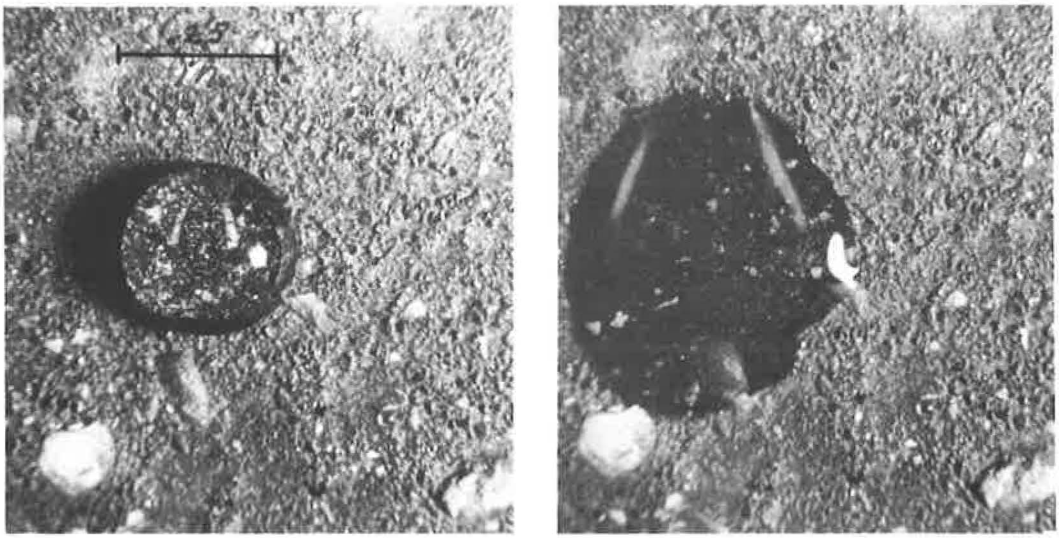
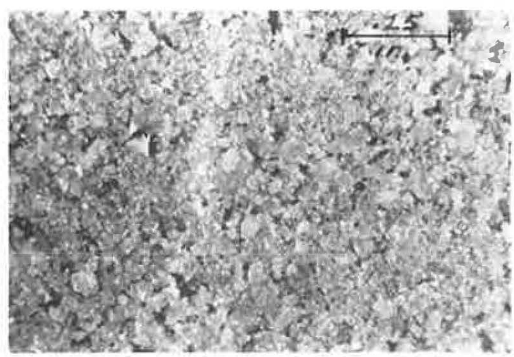


Figure 10. Porous sand asphalt (Kentucky rock asphalt) after rain.

Figure 11. Particle orientation of compressed fine sand; flat sides tend to be horizontal.



have performed about equivalent to bituminous concretes containing natural sands and crushed limestone coarse aggregates. All-limestone sand asphalts have performed about the same as all-limestone bituminous concretes. Sand asphalts containing all-natural sands have tended to exhibit higher skid resistance. Variability in shape, texture, and composition has affected performance. A crushed quartz sand in a dense sand asphalt is showing very good skid resistance after a year under severe traffic. A porous sand asphalt containing selected quartz sand less angular than crushed sand has shown superiority over the same sands in denser mixtures. The ultimate combination of high porosity and sharp, angular (crushed quartz) sands or other hard vesicular sands such as slags, scoria, or expanded shales has not been field tested. Performance equations indicating statistical confidence limits with respect to time and accumulated traffic are yet to be developed. Performance equations are needed to determine which types of surfaces and materials meet minimum standards for skid resistance.

Porous sand asphalts may be considered to possess almost all of the attributes of a popcorn mix or an open-graded plant-mix seal. They do not have comparable pore sizes. For instance, unless a porous sand-asphalt surface is prewet before the ASTM E 274 skid test, the water sprayed in front of the test wheel will not have significant time to wet or be blotted into the surface. The effect on the skid number might be about the same as if the test were made on a dense, nonwet surface. On the other hand, a fully wet, but unsaturated, porous sand asphalt may imbibe the sprayed water very quickly.

Other Attributes

Sand-asphalt surfaces, especially the more porous ones, generate minimum tire noise and tend to damp other noises generated by a vehicle. Under-car noise caused by splash and spray in wet weather is reduced. Significantly, the spray generated by vehicles is reduced unless water is in ponds or the surface is flooded.

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