Michigan's Experience With Different Materials and Designs for Skid Resistance of Bituminous Pavements

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•WITH THE rapidly rising number of vehicles on the road, it is not surprising that there is a corresponding rise in the number of vehicular accidents. Factors contributing to this include human behavior, vehicle mechanical failure, environmental conditions, road layout, and pavement surface. To tackle all these problems is a task for people of diversified interests. This report intends to isolate one of these factors, pavement surface, and to report on the work performed during the past 4 years by the Michigan Department of State Highways in improving skid resistance of pavements.

Accumulations of deposits on the road surface, such as rubber particles from tires, mud film, and oil and grease drippings from auto crankcases, are among the factors that contribute to slippery pavements, especially at the beginning of a rain after a long, dry spell. Excess surface bitumen and polishing of the coarse aggregate particles also contribute measurably to slippery pavement conditions.

An example of a slippery pavement caused by polished coarse aggregate is shown in Figure 1. The reflection of light from the pavement surface is a good indication that it may be slippery. A close-up of a sawed pavement core taken from this surface is shown in Figure 2. The coarse aggregate particles have become oriented in such a way that their flat faces are exposed to the surface and subject to subsequent polishing by traffic. When this same specimen is turned at an angle, as shown in Figure 3, one can see the oily bitumen absorbed into the surface of the coarse aggregate particles. This adds to the problem under wet conditions.

Although all coarse aggregate particles will eventually polish and exhibit these characteristics, experience indicates that some carbonate aggregates such as limestone, particularly the softer type, will polish at a faster rate than the harder or noncarbonate aggregates. On the other hand, experience indicates that fine aggregate particles produce a sandpaper surface texture that offers skid resistance. As the fine particles are gradually lost through wear, the surface rejuvenates itself and the sandpaper texture continues.

Although a sandpaper surface texture offers a skid-resistant surface, the effect of this sandpaper texture becomes minimized as vehicle speeds increase, particularly when the pavement is wet. Some engineers explain this as being due to hydroplaning of the tire on a water film. To nullify this, one might consider constructing a surface having sharp aggregate particles that protrude through the water film to make contact with the tire at higher speeds.

Most accidents occur in heavy traffic as vehicles approach intersections or other critical areas that may cause drivers to brake. Normal maximum speeds in these areas are below 40 mph. Therefore, in the interest of confining ourselves to a specific type of condition, let me further isolate this problem to surfaces that will be subjected to speeds under 40 mph.

Correcting these critical conditions usually involves resurfacing, commonly performed by placing a bituminous mat on the old surface. So let us further narrow the scope of this study to fine-textured, bituminous, skid-resistant surfaces.

Paper sponsored by the Committee on Bituminous Aggregate Bases and presented at the 49th Annual Meeting.

Figure 1. Slippery pavement surface of polished limestone.

Figure 2. Pavement cross section showing oriented flat particles.

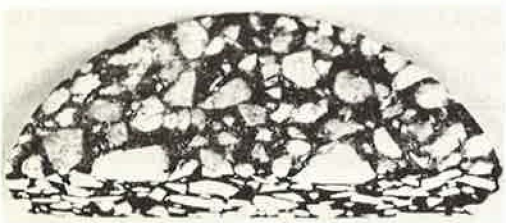

Figure 3. Pavement core showing aggregate particles in oily polished surface.

A statewide search was conducted to obtain different types of hard aggregates that could be crushed and used to produce fine-textured, bituminous surfaces. Also, preliminary laboratory studies were made to consider maximum particle size, gradations, bitumen content, mineral filler content, air void, and stability. To further supplement this investigation, a contract was entered into with the American Oil Company to allow preliminary skid studies to be conducted on its circular test track over short sections using different mixes.

Based on information obtained from all of these sources, a number of different types of materials and designs were used to produce skid-resistant surfaces at selected critical areas in the southern part of Michigan. The following are some of the materials used in these installations. A brief description is given of each.

SANDSTONE

This aggregate was a sandstone from the Grindstone City area of Michigan's "thumb" region; it is geologically identified as the lower Marshall sandstone formation, Pointe Aux Barques members. Large broken pieces of old, seasoned, discarded grindstones, which were processed years ago, were used as raw material for this project. Pieces containing excessive amounts of the finer grained brownish layers were generally not used. Freshly quarried sandstone from this source is reported to be somewhat "friable," and may require seasoning in the open air to harden the cementing material that holds the sandstone grains together.

The material was put through a crusher, and that portion still exceeding 3/8 in. was passed through the crusher a second time. These 2 crushings were combined and resulted in the following average gradation:

Sieve	Percent Passing
3/8 in.	100
No. 4	64
No. 8	44
No. 30	35
No. 100	24
No. 200	8

Physical characteristics of the material tested in the central laboratory were as follows:

Soundness, percentage of loss	57
Los Angeles A abrasion, percentage of wear	59
Specific gravity, dry basis	2.2
Absorption, percent	7.2

Figure 4. Crushed sandstone surface 4 years after construction.

Figure 5. Close-up of sandstone surface 4 years after construction.

Because the crusher-run material appeared to contain sufficient fines, no additional sand was added to the initial mix design. Several bitumen contents, varying from 8 to 10 percent, were tried, but the resulting mixture was tough to handle and produced a nonuniform, open-textured mat. After some experimentation, the mix design was changed by adding 1 part fine sand to 5 parts crusher-run sandstone and 9.5 percent 60 to 70 asphalt. Commercial mineral filler was not added to this mixture. This mixture produced a uniform-textured, skid-resistant surface and was used on 3 intersections in the Bay City area. Normally, a gradation of this type would use about 6.5 percent asphalt; however, because of the high absorption of this material (7.2 percent), it was necessary to raise the bitumen to about 9.5 percent in order to produce a serviceable pavement. Figure 4 shows a typical intersection after 4 years of service where this sandstone mixture was used, and Figure 5 shows a close-up of the sandpaper surface texture. After several months of wear, the larger sandstone particles began to show a dishing effect as shown in Figure 6. This has not detracted from the excellent service performance of this surface after 4 years of service under moderately heavy traffic; rather, it is felt that skid resistance characteristics have improved.

QUARTZITE

The aggregate used is identified as Ajibik quartzite and was obtained from the Upper Peninsula. The crusher-run material contained about 17 percent passing the No. 200 mesh sieve, which was considered somewhat high for a proper mix design. Consideration was given to washing a portion of the crushed material and blending the washed and unwashed stockpiles in proportions that would produce about 7.5 to 10 percent passing the No. 200 sieve. Inadvertently, the producer washed all the crushed material produced, resulting in the following gradation:

Sieve	Percent Passing
No. 8	100
No. 16	72
No. 30	43
No. 50	25
No. 100	11
No. 200	4.5

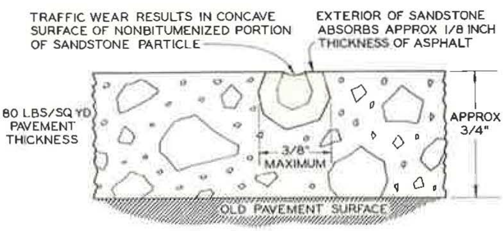

Figure 6. Result of traffic wear on larger particles of crushed sandstone.

Based on laboratory-prepared Marshall specimens and the appearance of a trial pavement surface, the mix design for the major portion of the project was set at 6.5

Figure 7. Crushed quartzite surface 3 years after construction.

Figure 8. Close-up of quartzite surface 4 years after construction.

percent 60 to 70 asphalt; 4.0 percent fly ash was added as mineral filler to make up for the fines lost through washing, and the remainder was quartzite crushings. No other aggregate was added for this mix design. Figure 7 shows a typical surface after 3 years of service in the Flint area. Some loss was experienced where traffic entered from a side gravel road causing considerable localized abrasion; however, the rest of the surface is in good condition. Figure 8 shows a close-up of this excellent skid-resistant surface.

Stripping tests performed on quartzite have usually indicated poor adhesion of the asphalt to the quartzite surface in the presence of water. The amount of stripping may vary, depending on the sources of the materials used. For this reason, on one additional project a heat-resistant, anti-stripping material was added to the asphalt cement before incorporation in the mixture. An intersection north of Flint was selected for this application to determine by actual service whether any differences show up after service between the quartzite mixtures containing asphalt with and without the additive. One percent of heat-resistant, anti-stripping additive was added to the 60 to 70 asphalt cement. A stripping test was performed in the laboratory on a mixture prepared with this quartzite (P8-R16) and 4.5 percent asphalt cement containing the additive. After curing, the mixture was subjected to a boiling test. Eighty percent of the asphalt containing the additive was retained on the quartzite, as compared to only 20 percent of the asphalt without the additive on a similar mixture. After 4 years, the surface containing the additive appears to show somewhat less wear than the surfaces constructed with untreated asphalt. However, both areas exhibit satisfactory durability and excellent skid resistance.

CRUSHED BEACH PEBBLES

The aggregates used were crushed pebbles obtained from beach deposits on the Lake Superior shore at the east end of the Upper Peninsula. After many years of grinding wave action on the aggregate particles, only the hard pebbles remain. The deposit is quite extensive along the lakeshore in this vicinity and is used as a source of pebbles for polishing, for decorative panels, and for other applications.

It was desired to crush the pebbles, ½ in. or larger, to 100 percent passing the No. 8 sieve; however, difficulties were experienced with the small crusher used for this purpose. Therefore, it was decided to accept the material as produced with the following average gradation:

Sieve	Percent Passing	Sieve	Percent Passing
⅜ in.	100	No. 30	30
No. 4	97	No. 50	19
No. 8	70	No. 100	11
No. 16	47	No. 200	5.5

Figure 9. Crushed beach pebbles 3 years after construction.

Figure 10. Close-up of beach-pebble surface 4 years after construction.

The mix design used was 5.7 percent 60 to 70 asphalt and 2.0 percent fly ash mineral filler; the remainder was crusher-run beach pebbles. No other aggregate was added to this mixture. Figure 9 shows a typical surface 3 years after construction at an intersection south of Flint. Figure 10 shows a close-up of the surface after 4 years of service. This surface is in fair condition; however, because of relocation of the roads in this area, part of this project was resurfaced last year.

TRAPROCK

The aggregate used was predominantly of basic igneous origin and was obtained from Michigan's Upper Peninsula. Because of the high amount of stone dust, the crushed material was washed, resulting in the following gradation:

Sieve	Percent Passing
No. 8	100
No. 16	76
No. 30	44
No. 50	22
No. 100	10
No. 200	6.6

The mix design called for 6.1 percent 60 to 70 asphalt plus 3.5 percent added fly ash mineral filler; the remainder was crushed traprock. No other aggregate was added to this mixture, which was used at an intersection south of Flint. Figure 11 shows the surface after 3 years of service. Considerable areas of the surface were worn completely through to the old pavement. No detour provisions were made, and heavy traffic was permitted to traverse the uncured, warm mat, resulting in premature wear that was evident within a few days after construction. I believe this mix would have proved more durable if traffic had not been permitted on the warm surface during construction.

Figure 11. Crushed traprock 3 years after construction.

SYNTHETIC BITUMEN AND NATURAL SAND

Previous experience indicated that, when certain synthetic bitumens were mixed with

Figure 12. Synthetic bitumen and sand 1 year after construction.

Figure 13. Sand-emulsion surface 4 years after construction.

sand, they exhibited promising skid resistance because of what appeared to be a noticeable rejuvenation of the sandpaper texture. This mixture was placed at a rate of 80 lb/sq yd on a section of I-96 about 50 miles west of Detroit. During the start of the first winter, sections of the pavement peeled off as shown in Figure 12. The rest of this surface was later bladed off. It was determined that considerable hardening of the bitumen occurred within a few months resulting in penetrations approaching zero. It is believed this contributed to the loss of adhesion between the thin bituminous mat and the underlying concrete pavement.

HOT ASPHALT EMULSION AND SAND

In recent years the asphalt emulsion industry has promoted the use of hot emulsion sand mixtures for skid-proofing purposes, and other states have reported satisfactory service with these mixtures. A mixing grade emulsion was used for this purpose; the producer claimed that the bitumen residue has certain thixotropic characteristics, thus permitting higher bitumen contents to be used in the mixture without danger of flushing. A fine aggregate passing the No. 8 sieve was mixed with about 10.8 percent emulsion resulting in about 7.5 percent residue. The temperatue of the mixture delivered to the street ranged between 245 and 270 F. Figure 13 shows a typical pavement section after 4 years of service, and Figure 14 shows a close-up of the fine sandpaper texture. This road is in good condition and offers a skid-resistant surface.

SAND ASPHALT

Although most of the previous materials and designs exhibited excellent skid-resistant properties, they were costly to construct primarily because of special handling of materials that are not normally used for paving purposes. On the other hand, it has been determined that ordinary sand-asphalt mixtures produce satisfactory although not high skid-resistant surfaces. Because sand-asphalt mixtures are less costly, it was decided to use them for much of the remainder of the skid-proofing program during the next several years.

At the beginning of the first winter season, some sand-asphalt surfaces showed delamination in the wheel tracks; that is, about ⅛-in. layers would separate from the rest of the mat. Figure 15 shows a typical example of such a road, and Figure 16 shows a detail of this phenomenon.

Although some theories have been proposed as to the cause of this, the writer has reservations about these explanations. Of more importance is the fact that solutions have been found to reduce this type of failure. After several years of observation, it was noted that bituminous mixtures with sands that are predominantly a one-sized "belly" type often exhibit this delamination, while uniformly graded sands very seldom show any delamination.

Figure 14. Close-up of sand-emulsion surface 4 years after construction.

Figure 15. Delamination of sand-asphalt surface 1 year after construction.

STONE-FILLED SAND ASPHALT

Another solution to the delamination problem is to tie the 1/8-in. top layer to the lower main portion of the mat by introducing coarse aggregate (3/8 in. top size) into the sand-asphalt mix. Figure 17 shows this technique of tying the upper and lower layers together. Satisfactory performance has been observed when this technique is used with the coarse aggregate content ranging from 10 to 25 percent. Figure 18 shows a pavement in Detroit with a stone-filled sand-asphalt mixture after 4 years of service. Figure 19 shows a close-up of the stone particles sticking up above the sand-asphalt mortar. Because there are very few exposed stone particles, a softer type of aggregate such as limestone may be used without concern regarding the polishing effect.

ASBESTOS FIBER AND SAND ASPHALT

Experience indicates that, within certain limits, leaner mixes exhibit better skid resistance than bituminous pavements designed at their optimum bitumen and mineral filler content. However, these leaner mixtures may show faster wear than corresponding surfaces having optimum designs. In an attempt to improve the durability of these mixtures, short fiber asbestos was added as filler; because of higher absorption, it allows more asphalt to be held in the mix. Three intersections were constructed with this material, all on Telegraph Road in the Detroit area. A typical design used is as follows:

Material	Percent	Material	Percent
Sand	87.5	Fly ash	2.0
Asbestos	2.0	Asphalt	8.5

Figure 20 shows a typical area in Detroit after 4 years of service. It is generally in good condition except for the fillet areas that were manually placed and cooled before

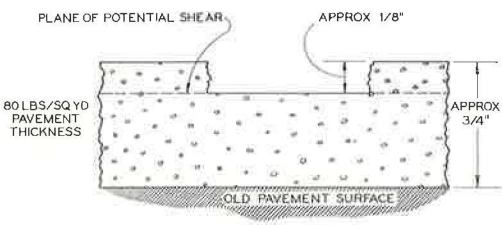

Figure 16. Cross section of delaminated sand-asphalt surface.

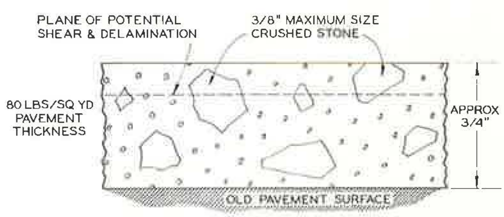

Figure 17. Cross section of stone-filled sand-asphalt surface.

Figure 18. Stone-filled sand-asphalt surface 4 years after construction.

Figure 19. Close-up showing stones sticking out of stone-filled sand asphalt.

they were properly compacted, resulting in some raveling. Figure 21 shows a close-up of the sand-asbestos-asphalt surface texture that exhibits satisfactory skid resistance.

SINOPAL AND SAND ASPHALT

During the period of placing the other experimental skid-resistant surfaces, a synthetic aggregate, which is a product of fluxed silica and dolomite, was shipped in from Europe. This is a white aggregate having a hardness of about 6 on the Mohs' scale of hardness. One part of the synthetic aggregate was mixed with 2 parts of natural sand, to which was added 2.5 percent limestone filler and 6.5 percent 60 to 70 asphalt. This was laid ½ to ¾-in. in thickness in the Benton Harbor area.

Figure 22 shows this surface after 4 years of service. The lighter colored areas shown in the right 2 lanes have the Sinopal added, while the darker areas in the left 2 lanes are mixtures of sand asphalt without Sinopal. Figure 23 shows a close-up of the Sinopal surface; the white particles of Sinopal can be seen exposed at the surface. This surface, in general, is in good condition and exhibits good skid resistance.

CONSTRUCTION NOTES

Motorists are sometimes warned of freshly laid bituminous surfaces by a sign indicating "slippery when wet." Figure 24 shows a freshly laid bituminous mat constructed with MC-3000 liquid asphalt. The left foreground surface was laid the day before, while the rest of the surface, which appears spotted, had just been completed when it was rained on. After 1 day of curing and weathering, water wets the pavement. However, as shown by the close-up in Figure 25, water globules have formed on the mat of the fresh surface. This nonwetting phenomenon of a fresh bituminous surface may contribute to slippery pavements when wet.

Psychologically, when a driver observes a smooth wet newly constructed bituminous surface, he may be inclined to apply brakes to slow down. Because of the nonwetting phenomenon and because the sandpaper texture has not yet developed, the driver may lose control of his vehicle on the slippery pavement. Therefore, it was felt that something had to be done to improve the initial skid resistance of pavements that ultimately should offer good skid resistance.

After considerable experimentation, a procedure was developed to produce an

Figure 20. Raveled fillets of sand-asbestos surface 4 years after construction.

Figure 21. Close-up of sand-asbestos surface 4 years after construction.

Figure 22. Sinopal-sand surface 4 years after construction.

Figure 23. Close-up of Sinopal-sand surface 4 years after construction.

Figure 24. Freshly laid bituminous surface after rain.

Figure 25. Close-up of fresh, oily, nonwetting bituminous surface after rain.

Figure 26. Spreading precoated sand on unrolled bituminous mat.

Figure 27. Spreading precoated sand without deflector (most of sand falls on shoulder).

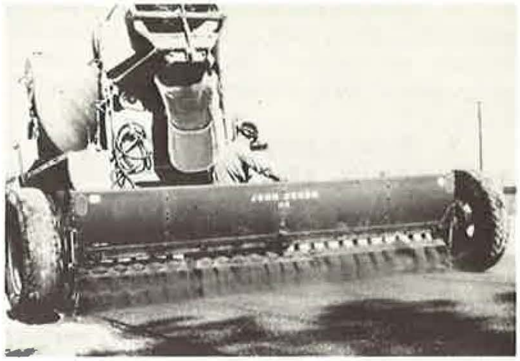

Figure 28. Seeder used for spreading precoated sand leaves ridges.

Figure 29. Rolling pavement after sand application.

Figure 30. Precoated sand on mat of partly rolled surface.

initial skid-resistant bituminous surface by applying hot sand, precoated with about 1 percent asphalt cement, on the unrolled mat behind the paver. This is then rolled into the surface and reduces the initial slickness. About 2 to 5 lb/sq yd of this precoated sand is sufficient; more may produce a ball-bearing effect, which can also be dangerous and may mar the pavement surface when bunched-up sand is rolled into the mat.

Figures 26 through 30 show some typical equipment used in this technique. The spreader shown in Figure 27 is not equipped with a deflector, thus allowing about $^2/_3$ of the precoated sand to be wasted on the shoulder. Using a seeder, as shown in Figure 28, sometimes leaves ridges that subsequently mark the pavement.

CONCLUSION

All the experimental surfaces start out with an initial average skid-resistance coefficient of friction of more than 0.45 (Fig. 31). The sandstone surface had an initial coefficient of 0.74, the quartzite surface of 0.71, the crushed beach pebbles of 0.63, and so on. There is a dip in all the curves after 1 year of service followed by an increase and leveling off of the coefficients. After 4 years of service, the sandstone and quartzite surfaces with coefficients of 0.57 and 0.58 are higher than the rest of the materials used in this study.

Considering that a satisfactory coefficient of friction should be more than 0.35 or 0.40, it is indicated that excellent skid resistance can be obtained by using special hard aggregates in the bituminous surfaces. However, the uniformly graded sand-asphalt mixtures offer a satisfactory skid resistance and have proved through service to be durable. Therefore, currently many of the critical areas on Michigan trunk lines are being resurfaced with the more economical sand-asphalt mixtures.

After observing these bituminous skid-resistant surfaces for 4 years, we feel that the following 10 items are worthy of consideration.

1. Soft coarse aggregates such as the carbonate types may polish faster than the harder aggregates. However, all coarse aggregates will eventually polish under traffic.

2. Fine aggregates (passing No. 8 seive) usually wear away exposing new ones before they become polished; therefore, they offer skid resistance at lower speeds (below 40 mph).

3. Uniformly graded fine aggregates resist wear better than nonuniformly graded ones and are not prone to surface delamination.

4. Angular fine-aggregate particles offer slightly better skid resistance than rounded sands.

5. Natural sand, well-graded and containing predominantly hard particles (5.5+ on Mohs' scale), offers satisfactory skid coefficient (0.40 to 0.50) and may be considered over the special aggregates for economic reasons.

6. Fresh bituminous surfaces are oily and nonwetting and are initially slippery when wet. This may be corrected by the application of sand, precoated with 1 percent asphalt, to a mat before rolling.

7. Mats of 80 lb/sq yd appear to be the desired application rate for skid-proofing purposes. A lesser thickness may wear prematurely and may peal off; a greater thickness may rut or shove.

8. Addition of mineral filler and asphalt should be kept slightly below optimum to obtain satisfactory skid resistance.

9. Thin mats are best applied at 60+ F air temperatures to obtain satisfactory compaction before chilling.

10. Existing surfaces must be thoroughly cleaned and have a light application of tack coat before thin bituminous skid-resistant mats are placed.

	0	1/2	1	2	3	4
	1965	1966 Spring	1966 Fall	1967	1968	1969
QUARTZITE	71	52	50	57	54	58
SANDSTONE	74	54	48	53	57	57
SAND-EMULSION	59	48	46	54	54	56
CRUSHED BEACH PEBBLES	63	47	46	44	47	52
SYNOPAL-SAND	47	41	39	54	47	49
STONE-FILLED SAND	52	41	37	45	45	48
ASBESTOS-SAND	62	39	36	43	44	46
SAND-ASPHALT	47	41	41	52	47	50

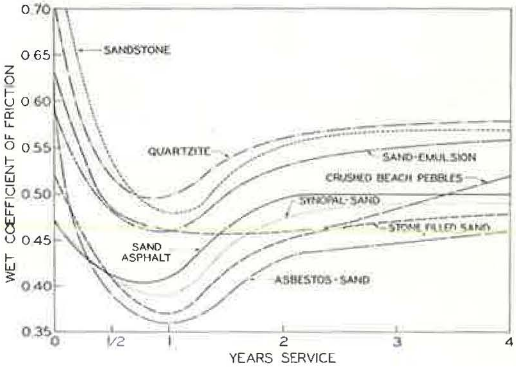

Figure 31. Pavement skid-resistance coefficients of different materials versus years of service.