EVALUATION OF OPEN-GRADED PLANT-MIX SEAL SURFACES FOR CORRECTION OF SLIPPERY PAVEMENTS

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This paper presents an extended evaluation of skid characteristics of various experimental plant-mix seal (PMS) and dense-graded hot-mix surfaces. The evaluation was performed on 1,000-ft (304.8-m) duplicate sections on US-190 in the Baton Rouge area. The sections consisted of a dense-graded gravel hot-mix surface of approximately 1-in. (25-mm) thickness and 3 PMS surfaces (crushed gravel, slag, and expanded clay) of $^5/_8$-in. (16-mm) thickness. Evaluation of these surfaces consisted of skid measurements according to ASTM E 274. Four-year data on the frictional performance of these surfaces have indicated that, in general, the PMS surfaces seem to possess the most desirable features with respect to constructability, skid resistance, texture, and drainage; specifically, the expanded clay and slag PMS surfaces show higher initial skid numbers and are able to maintain these numbers over an extended period of time under light and heavy traffic conditions; in addition to providing high skid resistance these PMS surfaces tend to reduce the potential for hydroplaning and ice glaze; and, in general, PMS surfaces provide flatter friction-speed gradients than does the corresponding hot-mix surface. The paper also provides information on the factors to be considered during the design and construction of these PMS surfaces and supplementary specifications for their design, construction, and acceptance.

•SKIDDING is caused by the interaction of 3 factors: the driver, the vehicle, and the roadway. Although it has not been possible to isolate human factors that contribute to skidding, considerable effort has been expended to accurately represent the roadway factor with emphasis on the frictional properties of the pavement surface and on the mechanism for surface renewal and prolonged high skid resistance. This paper is concerned with Louisiana's approach to providing skid-resistant surfaces by using bituminous surfaces.

MECHANISM FOR PROVIDING SKID RESISTANCE

A pavement becomes slippery when lubrication exists in the tire-surface contact area, when the inherently high skid resistance of a new surface has been worn or polished away by traffic, or when vehicle speeds are high enough to reduce hydrodynamically the tire-surface contact below the level required for vehicle maneuver (1). The mechanism for providing and maintaining prolonged high skid resistance should use an aggregate-binder combination that would provide adequate microtexture in the pavement and ample and quick water drainage.

In 1969, Louisiana initiated a study to determine which mechanism would provide the best nonskid surface and maintain the lowest skid decay rate. Figure 1 is a block diagram of the methods and materials that are generally advocated to improve surface skid resistance. Louisiana has had previous experience in the design and construction

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Figure 1. Bituminous surfacing methods to correct slippery pavements.

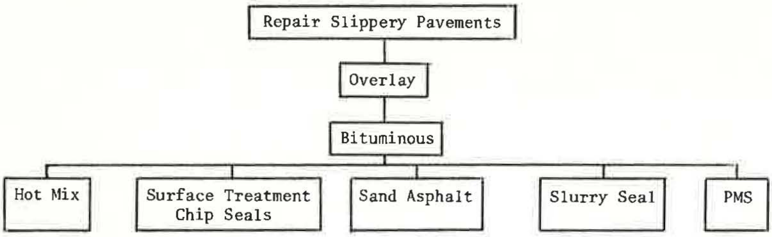


Table 1. Mix design data.

Type	Gravel Sand Hot Mix	Gravel PMS[a]	Gravel PMS[b]	Expanded Clay PMS	Slag PMS
Aggregate, percent	95	93	93	84	91
Asphalt cement, percent	5	7	7	16	9
Crushed on No. 4, percent	79	90	95	—	—
Asphalt cement grade	60-70	60-70	60-70	60-70	60-70
Laboratory specific gravity	2.34	—	—	—	—
Roadway, percentage of laboratory specific gravity	96.3	—	—	—	—
Voids, percent	5.3	—	—	—	—
Voids filled with asphalt, percent	68.2	—	—	—	—
Marshall stability, pounds	1,885	—	—	—	—
Flow, 1/100-in.	12	—	—	—	—

Note: 1 lb = 4.448 N. 1 in. = 25.4 mm.

[a]75 percent crushed faces. [b]95 percent crushed faces.

Table 2. Extracted aggregate gradation percent passing.

Sieve Size	Gravel Sand Hot Mix	Gravel PMS[a]	Gravel PMS[b]	Expanded Clay PMS	Slag PMS
3/4 in.	100	—	—	—	—
1/2 in.	98	100	100	100	100
3/8 in.	86	96	98	98	98
No. 4	59	53	46	49	41
No. 10	44	26	13	10	6
No. 16	—	—	—	—	—
No. 40	30	11	4	2	2
No. 50	—	—	—	—	—
No. 80	13	—	—	—	—
No. 100	—	2	—	1	1
No. 200	9	—	1	—	—

Note: 1 in. = 25.4 mm.

[a]75 percent crushed faces. [b]95 percent crushed faces.

Table 3. Summary of frictional performance, exterior lane, high traffic volume.

Age (months)	Cumulative Traffic (millions of vehicles)	Skid Numbers at 40 mph by Type of Surface			
		Gravel Sand Hot Mix	Gravel PMS	Expanded Clay PMS	Slag PMS
0	0	36	42	60	52
4	0.68	37	47	60	56
12	2.11	42	46	59	51
18	3.90	39	45	55	51
32	5.83	46	46	57	51
40	6.83	44	44	56	50
48	7.83	41	43	52	52

Note: 1 mile = 1.6 km.

of surfaces with all but the plant-mix seal (PMS) method the success of which was shown as early as 1967 by Mills (2) who reported on the frictional performance of these surfaces and compared PMS surfaces to dense-graded hot-mix surfaces with respect to skid resistance, drainage, and other characteristics.

DESCRIPTION OF TEST SECTIONS

Eleven different types of bituminous surfaces were used on US-190, a 4-lane divided highway in Baton Rouge. The project consisted of 10 duplicate 1,000-ft (304.8-m) sections. These were constructed on both the exterior and the interior lanes of the westbound roadway, which had an average daily traffic (ADT) of 9,510. The sections consisted of 3 hot-mix sections approximately 1 in. (25 mm) thick and 4 PMS sections ⅝ in. (16 mm) thick. Sand asphalt and slurry-seal mixes made up the rest of the sections and were approximately ¾ in. (19 mm) and ⅜ in. (10 mm) thick respectively. However, this paper will discuss only the dense-graded hot-mix and PMS sections. The hot-mix sections were made up of dense-graded mix consisting of crushed gravel and mixed with mineral filler and asphalt cement. The PMS sections consisted of 2 sections with crushed gravel, 1 with 75 percent crushed faces, and 1 with 95 percent crushed faces; the expanded clay aggregate PMS; and the slag PMS. Mix design data for these sections are given in Tables 1 and 2.

DESIGN OF MIXES

For asphalt concrete mixes, the Marshall method was used to determine asphalt content. The PMS mixes, because of their open texture and lack of mastic, did not lend themselves to the application of this design criterion and, therefore, optimum asphalt content was determined subjectively by visual observation. Briefly, the aggregate-asphalt mixtures were prepared with 3 asphalt contents, and the mix that indicated maximum aggregate coating with minimum asphalt runoff was selected as having optimum design asphalt content.

CONSTRUCTION CONTROL

At the plant, the problems associated with the control of asphalt concrete mixtures with respect to temperature and physical properties were minimal. However, PMS mixtures required special handling because of their higher asphalt contents and absence of fine material. To ensure adequate film thickness of the binder around the aggregate particles, we had to limit the mix temperature to 260 F (126.7 C). In 1 instance in which the temperature was about 300 F (148.9 C), the asphalt tended to run off the aggregate particles into the bottom of the truck. Although this did not prove detrimental to the mix on the roadway, it did cause some truck cleaning problems. These PMS mixtures, because of their open texture and absence of mineral filler, which is recognized as an antistrip additive, required a small amount of antistrip additive in the asphalt cement before mixing. Redicote 80S, 0.5 percent by weight of asphalt, was specified for these mixtures.

All sections were constructed in 1 lift. The mixture spreader had automatic screed control to the approximate thickness of 1 in. (25 mm) for hot mix and ⅝ in. (16 mm) for PMS.

The asphalt concrete mixtures were rolled by a tandem, a pneumatic, and a tandem roller, in that order. The PMS sections were rolled first with the tandem and then with the pneumatic rollers.

EVALUATION OF SURFACES

Major emphasis was placed on evaluating the skid, texture, and drainage characteristics of the various PMS surfaces.

Skid Performance

The frictional performance of the various surfaces with time and under wet pavement condition is indicated in Tables 3 and 4. The skid number (SN) relates to the friction factor f as determined by ASTM E 274. SN is the quantity 100 f; f = F/L where F is obtained in a strictly defined manner according to ASTM (3). Figures 2 and 3 show the graphical relationship of data given in these tables. The data represent 48-month skid measurements at 40 mph (64.4 km/h). The data collection on the PMS section with 75 percent crushed faces was discontinued because of unfavorable SNs. This section, therefore, is not referred to in the figures. The figures demonstrate the superior SN characteristic of the PMS surfaces constructed with manufactured aggregate. The gravel PMS, even with 95 percent crushed faces, failed to match the initial as well as the 48-month SN values of these 2 surfaces. Any corrective measure for control of surface slipperiness should have at least 2 characteristics: high initial skid resistance and no reduction of skid resistance with time and traffic. After 48 months of exposure to traffic (12 million vehicles), PMS surfaces have retained high frictional characteristics.

Essentially, traffic polishes aggregate. This reduces microtexture, which, consequently, reduces SN. If a renewal mechanism for surface microtexture is built into the pavement surface, prolonged skid resistance can be maintained. Expanded clay and slag aggregate seem to possess these surface renewal properties and are able to provide and maintain high, uniform skid resistance. However, these properties are lacking in the gravel PMS surface. The 48-month SNs for expanded clay and slag PMS, as demonstrated by both lanes (heavy and light traffic), seem to agree with the SNs reported by Mills (2). Furthermore, the average SN of 45 for asphalt concrete reported by Mills (2) also closely agrees with the present data. This comparison with Mills's data points out the magnitude of the SNs of PMS surfaces in general, but it is not based on the material component system (specifically with respect to aggregate type and asphalt content) used in the 4 western states of his study.

A surface should have a third characteristic for it to be an acceptable corrective mechanism, that is, it should show little or no decrease in skid resistance with increasing speed. Figure 4 is a speed-SN plot for hot-mix and PMS surfaces. The data represent 12-month SNs in an exterior lane. The expanded clay PMS surface does not follow the generally recognized association of flatter gradients with open texture. Possibly the expanded clay section, because of a higher than normal asphalt content, had shown some flushing and a change in texture, which seemed tighter than that observed during the initial period. The friction speed gradients for 48-month data had similar flat characteristics to those in Figure 4.

Texture and Surface Drainage

Most of the skid characteristics of the PMS surfaces are derived from microtexture, macrotexture, and surface drainage. Texture is a necessary prerequisite for generating friction, but it also provides channels by which water can escape from under the tire. Microtexture is what makes the aggregate particle feel gritty or smooth to the touch. Slag and expanded clay aggregate, because of their open texture and nonpolishing characteristic, provide an excellent mechanism for drainage escape. Surfaces provide, in addition to water escape channels, an excellent means of reducing "ice glaze" potential, which is prevalent after freezing rain and snow. This was observed during January and February 1973 when Louisiana was experiencing unusual snow and ice conditions. The hot-mix section, because of its dense texture, had a heavy glaze over it that made driving hazardous.

The finished texture of these PMS surfaces provides a pleasing appearance and a smooth riding surface. Figure 5 shows a series of photographs of the surface textures of the various surfaces discussed. The roughness of these surfaces, as measured by the BPR roughometer after 12 months of traffic exposure, ranged from 97 in./mile (1531 mm/km) for hot-mix surfaces to 86 in./mile (1357 mm/km), 81 in./mile (1278 mm/km), and 76 in./mile (1199 mm/km) for gravel PMS, expanded clay PMS, and slag PMS surfaces, respectively.

Because higher than normal asphalt contents are required for PMS surfaces, the problem of bleeding, due to either additional compaction or particle loss, cannot be ignored because it tends to induce plastic smoothing of the surface, thereby causing loss

Table 4. Summary of frictional performance, interior lane, low traffic volume.

Age (months)	Cumulative Traffic (millions of vehicles)	Skid Numbers at 40 mph by Type of Surface			
		Gravel Sand Hot Mix	Gravel PMS	Expanded Clay PMS	Slag PMS
0	0	44	43	57	53
4	0.46	50	52	66	59
12	1.42	51	52	66	61
18	2.13	52	49	61	57
32	2.68	48	54	60	55
40	3.34	50	47	66	56
48	3.98	45	44	61	58

Note: 1 mile = 1.6 km.

Figure 2. Skid performance of various PMS and hot-mix surfaces, exterior lane, high traffic volume.

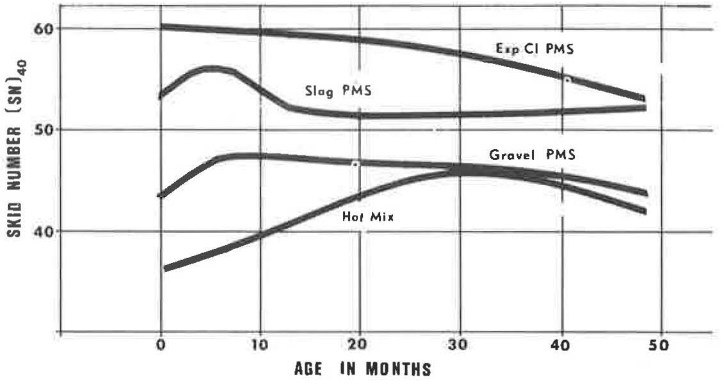


Figure 3. Skid performance of various PMS and hot-mix surfaces, interior lane, low traffic volume.

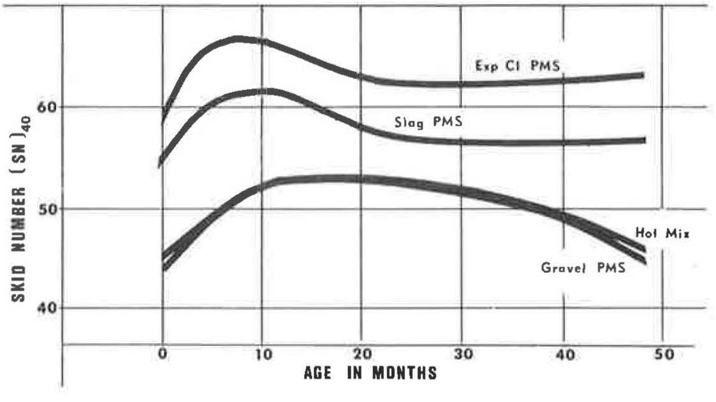
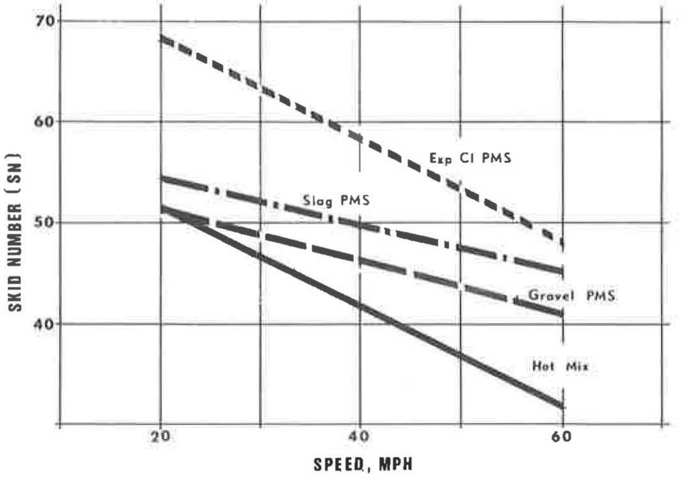


Figure 4. Friction-speed relationship of various PMS and hot-mix surfaces.



of texture and, ultimately, reduction in SN. However, this condition was not observed for any of the surfaces, except expanded clay, during the 4 summers that the surfaces were exposed. The initial low SN values observed soon after resurfacing can be attributed to thick asphalt films on protruding aggregate particles. This film soon wears off, and the full skid resistance of the surface is restored.

PRESENT CONSIDERATIONS

Since the construction of these PMS surfaces and because of their favorable skid performance, more PMS surfaces have been constructed. So far, the performance of these sections has been good.

Slag PMS

A slag PMS surface was constructed on a 0.846-mile (1.362-km) segment of I-10 in the New Orleans area in June 1970. Gradation and asphalt content were basically the same as for the slag PMS used on the experimental section (Table 1). The 6-lane segment of the highway carries more than 75,000 vehicles per day. The old surface had SN values in the low 30s and had a high percentage of wet accidents.

Figure 6 shows the skid performance of the 6-lane divided highway over a 30-month period. High initial SNs and subsequent uniformity are evident from these figures. However, the major benefit from the thrust behind the resurfacing is given in Table 5, which lists the accident data before and after corrective measures were taken. Accident data are given for each 6-month period before and after construction. The wet accident rate was computed on the basis of the number of vehicles exposed during wet conditions. Average hourly traffic and rain factor were used to compute exposure rate. The reduction in wet accidents is quite significant.

The microtexture and macrotexture of this PMS surface are such that during rainy weather the surface does not have the wet, shiny look generally associated with dense-graded asphalt concrete surfaces. And, bleeding due to high summer temperatures and traffic has not been observed in wheel paths.

Granite (Nepheline Syenite) PMS

This was the first use of the granite material in Louisiana. Two half-mile sections were constructed in January 1973, on segments of US-80, a divided 4-lane highway. The sections were constructed on westbound lanes that had an ADT of 10,080. The primary purpose for resurfacing was to provide a mechanism for water escape and reduce the hydroplaning potential rather than to increase the SNs that were in the upper 30s before the resurfacing. Although sufficient time has not elapsed to evaluate skid performance, 6-month SN data are in the middle 40s. The resurfacing has reduced the hydroplaning potential by providing easy drainage channels.

FUTURE CONSIDERATIONS

On the basis of data on various PMS surfaces, Louisiana has decided to made extensive use of slag and expanded clay aggregate PMS surfaces on all asphalt concrete roadways under heavy traffic (over 4,000 ADT/lane) (4). Supplementary specifications were prepared to cover design, construction, and acceptance procedures for these PMS surfaces.[1] Present policy also will allow gravel PMS on roadways having ADT between 1,000 and 2,000. Furthermore, during cool weather, the asphalt may be heated to 280 F (137.8 C) to allow for proper coating.

Design

At present, determining optimum asphalt content is based on visual observation of

[1] The original manuscript of this paper included the Appendix, Supplemental Specifications. The Appendix is available in Xerox form at cost of reproduction and handling from the Transportation Research Board. When ordering, refer to XS-53, Transportation Research Record 523.

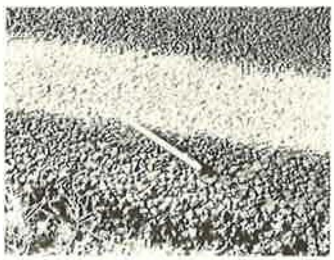
Figure 5. Textures of various surfaces.

dense-graded hot mix

expanded clay PMS

slag PMS

95% crushed gravel PMS



granite PMS (U.S. 80)

Figure 6. Skid performance of slag PMS surface.

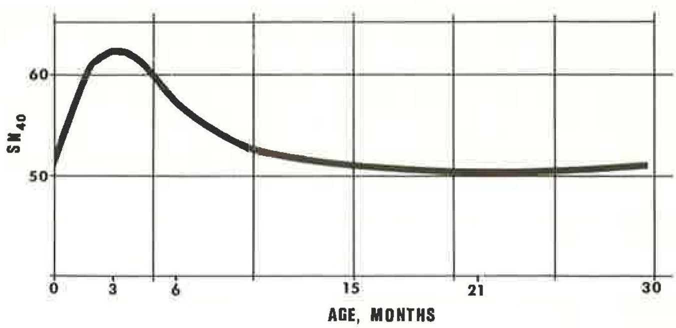


Table 5. Accident reduction before and after resurfacing.

	Accidents				Accident Rate		Accident Rate Reduction	
Period	Total	Wet	Percent Wet	Rain Factor[a]	Total (mvm)	Wet	Total (percent)	Wet
Before								
January 1970 to May 1970	37	21	56.7	70	3.78	114.1		
After								
June 1970 to December 1970	38	9	21.0	84	2.80	41.1	25.9	64.0
December 1970 to June 1971	17	2	11.8	29	1.72	28.6	54.5	74.9
June 1971 to December 1971	38	5	31.2	96	2.78	19.2	26.5	83.2

[a]Number of 1-hour periods during which 0.1 in. (2.5 mm) or more rain was recorded.

various asphalt content mixes and the boil test for stripping characteristic of aggregate asphalt mixes. Fifty-blow Marshall specimens are sometimes prepared to determine the breakage resistance of the aggregate particles. The drainage characteristic of a mix is determined by an outflow meter closely matching the device described by Brakey (5). In addition, the specimens are sawed in half for visual examination. The final recommendation on the job mix is made from the evaluation of the data. With the application of these design procedures, it has been possible to reduce asphalt content to 6.75 percent and 13.0 percent for slag and expanded clay aggregate PMS mixes respectively.

Construction

Although preparation of PMS mixes at the hot-mix plant is similar to the preparation of conventional mixes during construction, the mixing temperature should not exceed 260 F (126.7 C). Long hauls of more than 40 miles should be avoided or excessive "slumping" and separation may result. Any hand placement or raking tends to destroy uniform texture. This was observed on the granite PMS project in which the contractor had little choice at turnouts and connections; the texture at such locations was uneven and easily could be delineated from adjacent sections. A uniform tack coat is a must. In most cases, only a tandem roller is needed for compaction. And, because of the open-graded texture of these mixes, a means for preventing asphalt stripping should be provided.

These PMS surfaces should never be used without dense surface under them; otherwise, water will penetrate into the base and create adverse conditions due to their saturation. Drainage also should be provided when these mixes are placed in curb and gutter sections. If paved shoulders are used, the PMS surfaces should be higher than the adjoining shoulder.

Cost

Initial cost evaluation of plant-mix seals gave figures slightly higher than for conventional mixes—\$0.60 to \$0.65/sq yd for a ⅝-in.-thick surface (\$0.72 to \$0.78/m^2 for a 16-mm-thick surface). However, these materials, because of differing unit weights, will provide different coverage for a given thickness. For example, if gravel will cover 1.0 sq yd (0.86 m^2), an equal weight of slag will cover 1.2 sq yd (1.00 m^2) and expanded clay will cover 2.2 sq yd (1.84 m^2).

SUMMARY

Plant-mix seals seem to be the most promising resurfacing mechanism because they provide higher initial SNs, desired uniformity, and flat friction-speed gradients. An acceptable level of skid resistance can be maintained successfully if nonpolishing aggregates are used and if the treatment is applied carefully. In addition to providing high skid resistance, the surfaces also reduce the potential for hydroplaning. The safety features, coupled with a pleasing appearance, smooth, quiet riding surface, and reasonable cost, should make them the front-runners of available resurfacing methods.

ACKNOWLEDGMENTS

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