

# Virginia's Experience With Open-Graded Surface Mix

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The Virginia Department of Highways and Transportation has used the bituminous open-graded, porous friction course (PFC) since 1972 to resurface hazardous locations and roadways needing routine resurfacing. A before and after accident study of one location revealed a significant decrease in wet pavement accidents after it was paved with the PFC. Skid tests have revealed good to excellent skid resistance on all sections of the PFC. Some problems have been encountered with flushed spots in the pavement, minor raveling, deformation under severe traffic, damage from spilled fuel, and dirt in air voids. Most of these problems have been resolved, and future use will be determined by the long-term durability of the mix.

In Virginia, constant attention is directed toward the development, construction, and maintenance of pavement surfaces that provide good skid resistance. Most of the bituminous pavement surfaces on the state's highly traveled highways are dense-graded, although the surface texture may vary because of differences in aggregate gradations among the mix types used. When properly constructed, pavements having a dense-graded mix in the surface course usually give good skid resistance; however, to prevent wet weather skidding accidents requires a mix that will provide excellent drainage of surface water. For example, good surface drainage is a paramount consideration where thick surface water films are prevalent because of geometrics and where speed and traffic maneuvers create uncontrollable hydroplaning skids.

Because of the apparent need for an antihydroplaning mix, an open-graded, porous friction course (PFC) that had been used by several states was investigated. The PFC is designed as an open mix with interconnecting voids that provide drainage for heavy rainfall. The rainwater drains vertically through the PFC to an impermeable underlying layer and then laterally to the edge of the pavement.

In addition to providing high skid resistance during rainfall, the PFC, as compared to other mix types, reportedly (1)

1. Reduces spray and splash,
2. Enhances the visibility of pavement markings,
3. Reduces nighttime surface glare in wet weather,
4. Reduces tire-pavement noise, and
5. Allows use of thin layers and a minimum of material.

Virginia's experience has verified these advantages; however, noise measurements have not proved that porous friction course reduces tire-pavement noise. There was no appreciable difference in measured noise levels for a dense-graded mix and the PFC in a series of tests performed on a limited number of Virginia pavements.

## FIELD INSTALLATIONS

In 1972, PFC was used to resurface two short test sections. A 0.72-km (0.45-mile), two-lane section was placed on US-60 in central Virginia by using a light-weight aggregate in one lane and a crushed marble aggregate in the other. Some problems were encountered in controlling the aggregate gradation for the test section, which is often the case with small quantities of materials, particularly when a new gradation is used. The variability in the gradation caused some areas to be overly dense and to lack the desired permeability.

A second section, 0.6 km (0.4 mile) long on a four-lane roadway, was placed on US-23 north of the Virginia-Tennessee state line. Several wet pavement accidents had occurred at this location, and a before and after accident study was made to determine the safety benefits of the mix.

These two sections represented the initial experience with the PFC for both state and contractor personnel, although at least one Virginia contractor had worked with an open-graded mix in North Carolina. Initially, contractor personnel were rather dubious about the PFC and the required construction techniques; however, experience has tended to dispel their doubts.

In 1973 the PFC was placed on at least one section in each of the state's eight highway districts. As experience with PFC increased, problems were eliminated and workmanship was improved. Approximately 8.2 Gg (9000 tons) were placed in 1973, some of it on a section

of Interstate highway.

In 1974, approximately 22.7 Gg (25 000 tons) were placed, including 16.3 Gg (18 000 tons) on Interstate highways. Most of the Interstate sections on which the PFC was placed carry traffic volumes of about 13 000 vehicles per day on four lanes; however, a section on the Richmond-Petersburg Turnpike carries approximately 46 000 vehicles per day on six lanes.

## MIX DESIGN

The first of the two sections placed on US-60 in 1972 had the following design gradation:

Sieve	Percentage Passing	Sieve	Percentage Passing
12.5 mm	100	No. 8	10 to 30
9.5 mm	90 to 100	No. 16	0 to 20
No. 4	30 to 50	No. 200	0 to 4

The asphalt contents were 7 and 11 percent for the crushed marble aggregate and lightweight aggregate mixes respectively. The optimum asphalt content was selected by visual observation of trial mixes in the laboratory. The mixing temperature was specified to be between 104 and 132°C (220 and 270°F).

An 85 to 100 penetration asphalt cement was used for both the mix and the tack coat. A heavy tack coat [0.32 dm<sup>3</sup>/m<sup>2</sup> (0.07 gal/yd<sup>2</sup>)] was used to ensure an impermeable underlying layer. When applying the tack coat, the contractor had to raise the temperature of the asphalt very high before it would flow uniformly, which the contractor considered objectionable. A cationic emulsion tack coat was used on the US-23 job. Approximately 0.5 dm<sup>3</sup>/m<sup>2</sup> (0.1 gal/yd<sup>2</sup>) of residual CAE-2 (CRS-2) asphalt was applied on US-23, and, because of the ease with which it was applied and the apparent success achieved, a decision was made to allow either 85 to 100 penetration asphalt cement or cationic emulsion to be used on future jobs. Although the US-23 job was successful, during the long haul from the plant to the job the asphalt drained to the bottom of the truck, and the result was several fat spots in the pavement.

The mix gradation specified in 1973 was very similar to size No. 8 stone (ASTM D 692), which is usually available at all quarries. As before, the optimum asphalt content was selected through visual inspection of laboratory samples, including some observations of asphalt drainage from mixes placed on glass plates. The 1973 and current specifications are given elsewhere (4). The mixing temperature was specified to be 93 to 124°C (200 to 255°F); a temperature of approximately 107°C (225°F) was found preferable.

Very few changes were made in the specifications for 1974; however, the Federal Highway Administration (FHWA) design procedure (2) was examined with the idea of possibly improving the mix and refining Virginia's design procedure. The FHWA procedure consists basically of a gradation design and an asphalt content design. This procedure was used to develop designs for six mixes that had previously been used in pavement resurfacing, and the designs were compared to those actually used (3). Pavement performance was used to evaluate whether the correct design had been used. The design asphalt contents from the FHWA procedure were consistently lower than those used in the field, and only one aggregate type was found to require an asphalt content significantly different from that selected by the sample observation method. However, the design procedure was useful for certain aggregates. The method was adopted and is now being used to estimate optimum asphalt content; however, because Virginia's PFC gra-

dition is rather fixed, i.e., No. 8 stone, the gradation design was not considered useful.

## PROBLEMS

### Construction

The CAE-2 (CRS-2) tack coat, on occasion, tended to stick to truck tires, then drop off, and puddle, causing flushed spots. However, when the emulsion has been allowed to cure properly, it has proved to be satisfactory.

Problems have been experienced when the mixing temperature has not been properly controlled. An unsatisfactory pavement was obtained when the temperature of the mix was too high. Excess asphalt migrated to the bottom of the trucks and, when deposited in one area, formed flushed spots in the pavement.

Long hauls tended to magnify the problems of asphalt drainage in truck bodies and excessive cooling and lumping of the mix on the exterior surface. It is advisable to limit the plant-to-paver time lapse.

### Maintenance

No major maintenance problems have been experienced, although some minor ones have arisen. A section on I-81 consisting of crushed gravel appeared to be raveling approximately 6 to 12 months after construction. To determine future maintenance possibilities, a diluted cationic emulsion was applied to a short length of the section to arrest the raveling. The emulsion penetrated the PFC and will, it is hoped, provide an asphalt coating to prevent further raveling. The treated and untreated sections will be observed and compared.

At a toll booth on the Richmond-Petersburg Turnpike, on the lanes carrying heavy truck traffic, some deformation and densification are beginning to show approximately 1 year after construction, which indicates that possibly this mix should not be used under very severe traffic conditions.

The PFC is more susceptible to damage from spilled fuels than is a dense-graded mix, because spillage penetrates the mix and the underlying surface. Fuel spilled from an overturned truck on the Richmond-Petersburg Turnpike severely damaged a short section of pavement. This situation requires removal of the damaged mix, usually with a heater planer, and replacement with fresh mix.

Voids of cores from nine projects ranged from 21 to 32 percent, and these projects have maintained good drainage characteristics. However, examination of cores from the Richmond-Petersburg Turnpike revealed reduced voids in wheel paths and between wheel paths, apparently from the accumulation of dirt. The effectiveness of the PFC may be reduced if the environment is very dirty and dirt penetrates the voids.

## RESULTS

### Durability

One of the initial primary concerns with the PFC was the service life and general durability because the opengrading would expose the asphalt cement and thus make it subject to early oxidation and weathering. To prevent early deterioration due to oxidation and weathering, the mix is designed with thick asphalt films and should contain as much asphalt as possible.

Inasmuch as the oldest PFC in Virginia has been in service for only 3 years, it is not possible to reach any conclusions on its long-term durability at the present time.

### Stability

Rut depths were measured on 11 sections of open-graded surface mix and two sections of regular dense-graded surface mix. The open-graded mix had a rut depth range of 1 to 3 mm (0.04 to 0.12 in) and averaged 2 mm (0.07 in).

The dense-graded surface mix, which showed no visible rutting, had a rut depth of 3 mm (0.10 in), and the dense-graded section with some visible rutting had a measured rut depth of 7 mm (0.26 in). Therefore the rut depth and stability of the open-graded mix are equivalent to those of a good dense-graded mix.

### Skid Resistance

Table 1 gives the average skid numbers for some of the PFC pavements. Although not shown in Table 1, some of the sections have been tested at regular intervals and have not shown any appreciable change in skid resistance.

All of the sections have good skid resistance, and the first section, the one with lightweight aggregate on US-60, has a skid number of 72. This section has low traffic volume, but it is expected that similar results would be obtained under high traffic volumes.

Most of the sections have been placed for routine maintenance purposes; however, some were designed to reduce wet pavement accidents by enhancing the road's skid resistance. The section on US-23 had a high incidence of wet pavement accidents, which are believed to be caused by excessive surface water films. The excessive films were believed to be a result of the pavement geometry and surface type, so it was thought that a porous surface would alleviate the problem.

A survey of accidents 1 year before and 1 year after installation of the PFC revealed a significant reduction in wet pavement accidents. In the year before installation, 39 percent (7 of 18) of the accidents occurred during wet weather, but during the year after installation only 17 percent (2 of 12) of the accidents occurred during wet weather, which is considered normal. In this instance the benefits of the PFC are evident.

Other sections have been placed in locations that had experienced skidding accidents, but it is too early to evaluate their effectiveness.

### FUTURE PLANS

Evaluation of the PFC sections will be continued. Such courses probably will be used for some routine maintenance

overlays and at locations where wet pavement accidents are a problem. The durability of the mix will probably determine the long-range use.

### ACKNOWLEDGMENTS

When Virginia began using the PFC in 1972, North Carolina highway engineers who had considerable experience with the mix were consulted and provided invaluable assistance. The original specifications and construction procedures were patterned after those of North Carolina.

### REFERENCES

1. Open-Graded Asphalt Friction Courses. Asphalt Institute, College Park, Md., Construction Leaflet 10, Nov. 1974.
2. R. W. Smith, J. M. Rice, and S. R. Spelman. Design of Open-Graded Asphalt Friction Courses. Office of Research and Development, Federal Highway Administration, Interim Rept., Jan. 1974.
3. G. W. Maupin, Jr. Investigation of Asphalt Content Design for Open-Graded Bituminous Mixes. Virginia Highway and Transportation Research Council, March 1974.
4. Special Provisions for Bituminous Porous Friction Course. Virginia Department of Highways and Transportation.

## Discussion

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The author has pointed out asphalt drainage problems during transit from the mixing plant to the job site. This can possibly be avoided if the mix temperature is established on asphalt viscosity considerations. FHWA has recommended that the target mixing temperature be in the range that will correspond to asphalt viscosities of 7 to 9 cm<sup>2</sup>/s (700 to 900 centistokes) (5). The Pennsylvania Department of Transportation has designed and placed seven experimental sections of open-graded asphalt friction course from 1974 to 1975. According to our experience, the viscosity range should be 11 to 15 cm<sup>2</sup>/s (1100 to 1500 centistokes). We did not encounter any drainage or crusting problem within this range, even though the mix was hauled more than 32 km (20 miles) in some cases.

The mix gradation specified by Virginia in 1973 consists essentially of coarse aggregate only. However, FHWA has recommended that at least some fine aggregate be used to provide a choking action for the stabilization of the coarse aggregate fraction. Use of coarse aggregate alone is not only economical, but also should result in improved permeability. It is hoped that the continual evaluation of these experimental sections will indicate whether the fine aggregate is needed from the standpoint of stability and durability.

### REFERENCE

5. R. W. Smith, J. M. Rice, and S. R. Spellman. Design of Open-Graded Asphalt Friction Courses. Federal Highway Administration, FHWA-RD-74-2, Jan. 1974.

Table 1. Average skid numbers of typical PFC pavements, spring 1975.

Route	Year Constructed	Vehicles per Day per Lane	Skid Number <sup>a</sup>
US-23	1972	900	66
US-23	1973	900	66
US-460	1973	2650	64
US-460	1973	2200	60
US-60 <sup>b</sup>	1972	450	57
US-60 <sup>c</sup>	1972	450	72
US-60	1973	2000	54
US-301	1974	3700	54
US-17	1973	2950	58
US-301	1973	1050	60
US-29	1973	4300	60
I-81	1973	3400	68
I-81	1974	3250	60
Va-42	1973	1800	66
US-50	1973	1300	51

<sup>a</sup>Predicted car values from ASTM skid test trailer.

<sup>b</sup>Marble aggregate.

<sup>c</sup>Lightweight aggregate.

## Author's Closure

The temperature-viscosity curves of AC-20 asphalt cements obtained in the past under viscosity specifications were examined. They showed little variation, so the required mixing temperature was rather constant. We felt that it was preferable to specify the mixing temperature, which has been established by experience. Some of the drainage problems may be attributed to the fact that the mix is designed to have thick asphalt films and that sufficient fines to soak up excess asphalt were absent.

We do not use the fine aggregate for the choking action, and there have been no apparent problems with stability under normal use. As I indicated, rut depths for the open-graded mix are comparable to those for a well-designed dense-graded mix.