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16. Abstract Porous or permeable friction courses (PFC) are hot mix asphalt mixtures placed at the surface of a pavement structure in a thin layer to produce several benefits for the traveling public in terms of safety, economy, and the environment. It is a sacrificial wearing course consisting of an aggregate with relatively uniform grading and little or no fines and mineral filler and it is designed to have a high air void content compared to dense-graded mixtures. This document presents construction and maintenance guidelines for PFC which is based on a compilation of information from <ul style="list-style-type: none"> • published literature; • interviews with engineers and inspectors of TxDOT districts with experience in the construction of PFCs; and • onsite field observations during the construction of 10 PFC projects around the state. Construction guidelines are presented on mixture production, storage and transportation, surface preparation, mixture placement, compaction and joint construction, and mixture acceptance. Since most of the PFCs constructed in Texas have performed very well to date, there is little experience regarding maintenance of PFCs. Based on information from the literature, guidelines are presented on corrective maintenance, surface maintenance, winter maintenance, and rehabilitation.		13. Type of Report and Period Covered Technical Report: September 2005-August 2007	
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GUIDELINES ON CONSTRUCTION AND MAINTENANCE OF POROUS FRICTION COURSES IN TEXAS

by

Cindy K. Estakhri
Research Engineer, Texas Transportation Institute

Alex E. Alvarez
Graduate Student, Texas A&M University

Amy Epps Martin
Associate Research Engineer, Texas Transportation Institute

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

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CHAPTER 1.0 INTRODUCTION

Porous or permeable friction courses (PFC) are hot mix asphalt (HMA) mixtures placed at the surface of an asphalt pavement structure in a thin layer to produce several benefits for the traveling public in terms of safety, economy, and the environment. It is a sacrificial wearing course consisting of an aggregate with relatively uniform grading and little or no fines and mineral filler. It is designed to have a large air void content compared to dense-graded mixes. PFCs are defined in Item 342 of the 2004 Texas Department of Transportation (TxDOT) Standard Specifications book as a surface course of a compacted permeable mixture of aggregate, asphalt binder, and additives mixed hot in a mixing plant (1).

BENEFITS OF PFC

The most important benefit of PFC is increased safety during wet weather. The open void structure aids in the drainage of water and preservation of the surface friction. Benefits of PFC include the following (2):

- reduced risk of hydroplaning and wet skidding,
- decreased splash and spray,
- reduced tire/pavement noise,
- improved ride quality,
- improved visibility of pavement markings at night and in wet weather, and
- cleaner storm water runoff compared to dense graded mixes.

USES OF PFC

PFC can be used in new construction, major rehabilitation projects, and maintenance overlays (3). It is typically used as a sacrificial wearing course over dense graded mixtures or Portland cement concrete pavements in areas that experience high traffic volumes and moderate to heavy rainfall. PFC can minimize hydroplaning potential by providing drainage channels for water to flow beneath the pavement surface. This will also minimize splash and spray due to rain by reducing the surface water and glare at night during wet weather resulting in better visibility.

PFC should be considered when the cross slope is less than 2 percent and there are two or more lanes in one direction (3). While effective in removing water from the pavement surface, it is not a solution for correcting cross slopes.

PFC should not be used to correct severe rutting or depressions in the underlying pavement. These depressions will allow water to accumulate and may accelerate pavement damage. Ruts and depressions should be leveled with dense-graded mix prior to overlaying with PFC.

PFC can also mitigate flushing and bleeding problems. The open void structure allows the absorption of the free asphalt which may alleviate the bleeding pavement. This, however, may only provide a short term solution and may not prevent rutting or completely address the source of the distress (3).

Some of the areas where PFC should not be used include the following:

- Crossovers and Driveway Turnouts – These areas generally require a significant amount of hand work when placing the mix, and PFC does not lend itself to that level of workability.
- Areas with Severe Turning Movements – Areas that experience short radius turning are not recommended for placement of PFC. These areas are more prone to vehicle tire damage and can include intersections and driveway turnouts.
- Muddy and Sandy Areas – Any locations where mud or sand can be trafficked from unsurfaced driveways or side roads can clog the PFC.
- Areas Prone to Oil and Fuel Drippings – The dripping of oil or fuel from slow or stopped vehicles can cause the surface to soften and deteriorate.
- Digouts and Localized Areas to be Removed and Replaced (3) – PFC should not be placed in areas where a bathtub effect may be created. When sections of dense-graded pavement are removed, dense-graded mix should be used as a replacement material before overlaying with PFC.

PERFORMANCE

PFC performance includes durability and functionality. Whereas durability comprises moisture sensitivity and aging potential, functionality takes into account permeability and noise reduction.

Durability

The service life of PFC is highly variable and can range from 7 to 10 years. One of the factors that most influences mixture durability is the type of binder used. The majority of agencies reporting successful application of PFC are using modified binders. Tire rubber, SBS, and SBR-modified asphalt are now more frequently employed in PFC.

TTI researchers have also found that the durability of PFC mixtures is also affected by the quality of the aggregate (4). The quality of the aggregate affects the mixture's resistance to degradation under traffic and environment and also affects the bond strength between the asphalt and aggregate surface.

Raveling is the distress most frequently reported as the cause of failure in PFC mixtures. However, delamination is also cited as an important cause of failure in these mixtures. Raveling can be associated with aging binder, which can be the main cause, binder softening generated by oil and fuel drippings, and inadequate compaction or insufficient asphalt content. Important work remains to be done in assessing the aging potential of PFC mixtures and the resulting impact on durability.

Functionality

A functional life between 5 and 8 years is expected for PFC. Functionality is affected by air voids content reductions during service as a consequence of clogging. Therefore, in the absence of cleaning activities, the initial permeability and noise reduction capacity are expected to decrease such that, at the end of the functional life, PFC behaves like dense-graded mix.

When the infrastructure contributes a small amount of debris and high traffic speeds can be ensured, clogging may be delayed due to the existence of suction forces generated by high-speed rolling tires that effectively clean the PFC.

Europe and Japan are pursuing the extended noise reduction capability of PFC by means of a combined strategy that involves designing and constructing two-layer PFC, limiting construction of PFC to high-speed roads only, and applying frequent cleaning with special equipment. However, engineers in different agencies around the world do not agree on the convenience of cleaning techniques, and its practice is still not generalized. New technological developments (i.e., new Japanese cleaning technology) are modifying the current cleaning practices and maximizing the cost-benefit ratio of this practice.

Although high permeability is one of the main properties of PFC, the measurement of this parameter is not widely practiced since it is integrated into most mixture design procedures as air voids content, which is considered to be representative of drainability. However, many agencies in the United States do not specify the minimum air voids content.

The common approach to measure the drainage capacity of porous mixes in the field is the determination of the time of discharge of a specific water volume. In the laboratory, permeability has been measured using permeameters with either falling head or constant head.

Literature from Spain suggests that PFC mixtures are highly resistant to permanent deformation, and no laboratory tests are required to evaluate the material response for this type of distress¹. This is based on more than 20 years of performance data.

OVERVIEW OF THE PFC MIXTURE DESIGN PROCEDURE

To obtain the benefits described above, a mix design system that produces both a functional and durable PFC mixture is required. In Texas, the PFC mix design is currently defined in TxDOT Test Method Tex-204-F, Part V(5), and material requirements are defined in Item 342 of the 2004 TxDOT Standard Specifications book. Research report 0-5262-3 provides some recommendations for modifications to the mix design but these have not been implemented at this time (4). The following two types of binders are allowed in the specification:

- a Type I or II asphalt rubber (AR) defined in Item 300.2.I with a minimum of 15 percent by weight of asphalt of Grade C or Grade B crumb rubber defined in Item 300.2.G, and
- a PG asphalt with a minimum high temperature grade of PG 76-XX defined in Item 300.2.J with a minimum of 1.0 percent of lime by weight of dry aggregate and a minimum of 0.2 percent of cellulose or mineral fibers by weight of mixture.

Based on the type of asphalt selected, master aggregate gradation bands are provided in Item 342. Aggregates must also meet requirements in Item 342 that include coarse aggregate angularity, deleterious materials, soundness, abrasion resistance, and flat and elongated particles.

Following selection of materials, two replicate specimens [6 inches in diameter by 4.5 inches in height] at three selected asphalt contents are mixed, oven-cured for 2 hours at the

¹ Pérez, F., R. Miró, and A. Martínez. *Capas de rodadura: mezclas porosas y micros en caliente*. Curso sobre Estudio, Diseño y Control de Mezclas Bituminosas, Universidad Politécnica de Cataluña. 2005. [Spanish]. Unpublished.

compaction temperature, and compacted in a Superpave Gyrotory Compactor (SGC) at an N_{design} of 50. The three asphalt contents differ by 0.5 percent, and the minimum optimum asphalt content for PG and AR asphalts, respectively, must be 6.0 percent and 8.0 percent. According to Item 342, the asphalt content must be between 6 and 7 percent for PG mixtures and between 8 and 10 percent for AR mixtures. An optimum asphalt content is then selected based on the target laboratory density specified (between a suggested limit of 78 and a maximum of 82 percent according to Item 342 or equivalently between total AV contents of 18 and 22 percent evaluated using dimensional analysis) and the minimum requirements provided.

Next, specimens at the selected optimum binder content are produced for an evaluation of draindown (Tex-235-F), moisture susceptibility (Tex-530-C), and durability (Tex-245-F) (5,6). The optimum mixture must have a maximum draindown of 0.2 percent, where draindown is defined as the ratio of: the change in the weight of paper plate that the mixture is allowed to drain onto from a wire mesh basket at the plant mixing temperature for 1 hour to the original specimen weight. The moisture susceptibility of the optimum mixture is determined by boiling the loose mixture in water for 10 minutes and visually evaluating the percentage of stripping immediately and after 24 hours. The percentage of stripping after 24 hours is reported for comparison during production, and no requirement is provided in the TxDOT specification. The engineer may reduce or waive the sampling and test requirements for the boil test based on a satisfactory test history.

Finally, the durability of the optimum mixture is evaluated based on the percentage of Cantabro loss, where Cantabro loss is defined as the change in weight of the specimen before and after an abrasion test divided by the original specimen weight. The test involves placing a compacted specimen into the Los Angeles abrasion equipment without the steel balls and rotating the apparatus for 300 revolutions at 30 to 33 revolutions per minute. Table 4 in Item 342 suggests a maximum Cantabro loss value of 20 percent, but this value is reported for information only.

Item 342 of the 2004 TxDOT standard specifications integrates aging of the binder, but only during production. Aging ratio is defined as the ratio of the high PG temperature Dynamic Shear Rheometer (DSR) parameter ($G^*/\sin \delta$) of the extracted and recovered binder sample, and this same parameter evaluated on the original unaged binder. A maximum aging ratio value of 3.5 is specified.

BACKGROUND FOR CONSTRUCTION AND MAINTENANCE GUIDELINES

The guidelines presented in this document are a compilation of information obtained from three sources (2, 4):

- published literature,
- interviews with engineers and inspectors of TxDOT districts with experience in the construction of PFCs, and
- onsite field observations during the construction of 10 PFC projects around the state over the course of this 2-year research project.

Most of the PFC projects in Texas, which were designed according to 2004 TxDOT Standard Specification Item 342, are less than 3 years old. As a result, there is little to no experience in the districts concerning maintenance of these pavements. The maintenance guidelines presented in this document are a result of information from the published literature.

CHAPTER 2.0 CONSTRUCTION OF POROUS FRICTION COURSES

The construction of PFCs, in general, utilizes the current techniques applied to the construction of dense-graded mixes. However, there are some special considerations which should be implemented throughout the process.

MIXTURE PRODUCTION

Moisture Considerations

As in the production of dense-graded mixtures, PFC production requires special attention to aggregate moisture control. The mixing time and temperature should be controlled so that substantially all of the moisture is removed from the mix before discharging from the plant. 2004 TxDOT specifications (Item 342) require that the mixture contain no more than 0.2 percent moisture by weight which should ensure better control of mixing temperature and a more homogeneous mixture. Some states only require the use of aggregate in a surface dry condition for PFC production (7). The British Standard establishes 1 percent (by mass of the mixture at the required temperature) as the maximum moisture content for PA mixtures during construction (8).

Addition of Fibers

When asphalt rubber binders are specified, fibers are not incorporated. Cellulose or mineral fibers should be used when a PG 76-XX binder is specified. Conventional asphalt plants can be adapted to allow the incorporation of fibers with the installation of a fiber feed device as shown in Figure 1.

In batch plants, bags of fiber can be added directly into the pugmill where the bags melt, and the fiber is distributed into the mixture (9). When using a batch plant to produce mixtures with mineral fibers or cellulose fibers, it may be necessary to lengthen both the dry and wet mixing times to ensure fiber distribution. Drying time may also need to be increased if the production temperature is lower than that used for other types of mixtures.



Figure 1. Introduction of Fibers into Drum on IH-30 Project in Paris District.

Mixing Temperature

The binder supplier should be consulted to determine the appropriate plant mixing temperature. Minimum mixing temperatures must be maintained to ensure that the mix reaches the roadway at a temperature that provides for ease of placement. In addition, the maximum mixing temperature must also be monitored to prevent draindown of the binder. TxDOT specifications require that the maximum temperature not exceed 350°F prior to shipping the mix from the plant and that the mixture shall not be placed at a temperature below 280°F.

MIXTURE STORAGE AND TRANSPORTATION

Because PFCs may be prone to draindown, some DOTs limit mixture storage and transportation times. In 1990, the FHWA suggested that the combined handling and hauling of these mixtures be limited to 40 miles or 1 hour (10). In Britain, a maximum period of 3 hours is specified as acceptable for the whole process between mixing, placement, and compaction (11). TxDOT requires that PFC mixtures not be stored for a period long enough to affect the quality of

the mixture, nor in any case longer than 12 hours. Thus far, draindown of the binder has not been reported as a problem in the construction of PFCs in Texas.

Tarps are necessary to avoid crusting of PFCs during transportation. Insulated truck beds for transportation of PFC are required by some agencies. Item 342 does not require the use of tarps and insulated truck beds, although several TxDOT districts recommend that they be required on the job. In Britain, double-sheeted insulated vehicles are required to transport PFC mixtures (12). Truck beds should be prepared for transportation by using a full application of an asphalt release agent.

SURFACE PREPARATION

Any edge clearing (Figure 2) should be performed prior to placement of the PFC. These fines on the outside edge of the mat can cause the mixture to clog near the edge.



Figure 2. Edge Clearing that Can Cause Clogging of PFC Restricting Lateral Water Flow.

PFCs should not be considered as a layer to correct profile distresses or any kind of structural distress. Before placement of PFC, the pavement surface should be corrected to avoid zones that allow water accumulations (e.g., zones with permanent deformation). Lateral and longitudinal drainage of the underlying surface must be provided to guarantee adequate water discharge from the PFC.

Many TxDOT districts prefer the surface directly beneath the PFC to be a seal coat. This ensures an impermeable membrane to protect the underlying layers from surface water intrusion. The seal coat also helps to provide a good bond between the PFC and underlying surface, particularly for Portland cement concrete pavement surfaces. PFCs have also been placed over Type C dense-graded mixes in the San Antonio District; though on more recent projects, a seal coat is placed first. Waco has used PFCs over stone mastic asphalt (SMA) and seal-coated surfaces. Wichita Falls requires the underlying surface to be either an SMA or a stone-filled mix, followed by a seal coat. The Austin, Lufkin, Paris, Yoakum, and Houston Districts have used it over dense graded surfaces as well as seal-coated surfaces. Recently the Houston District has used PFC as the final riding surface over crack-attenuating mixes (CAM).

It is important to have an adequate tack coat to bond the PFC to the underlying surface. A good tack coat can also help to seal the surface from the intrusion of water from the surface. Item 342 states that the tack should be uniform and should be applied at a rate between 0.04 and 0.10 gal/sy residual asphalt as directed by the engineer. If there is a new seal coat underneath the PFC, some districts do not require a tack, although the Odessa District still required a tack coat on the new seal shown in [Figure 3](#) prior to placement of the PFC.



Figure 3. Application of PFC on Tacked, Newly Seal Coated Surface of IH 10 in Odessa District.

Figure 4 shows the placement of PFC on IH 30 in the Paris District. In this operation, the laydown machine is equipped with an emulsion tank which is sprayed immediately in front of the hot mix. This allows for a heavier and perhaps more uniform application of tack since construction vehicles do not drive on the tacked surface.



Figure 4. Laydown Machine with Tank for Applying Tack on IH-30 in the Paris District.

MIXTURE PLACEMENT

Material Delivery

It is very important to monitor the temperature of PFC as delivered to the roadway. Any cold spots will form lumps in the mix and must be removed. Some districts recommend the use of a material transfer vehicle (MTV) to minimize the need to remove large chunks of mix. Even with the MTV, there may still be small chunks of mix requiring removal and patching from the mat as shown in [Figure 5](#), which is in the Houston District on a project paved in early fall.



Figure 5. MTV Paving Operation (upper photo) and Areas in the Mat where Cold Chunks Required Removal and Patching (lower photo) on US 288 in the Houston District.

The windrow pickup process tends to exhibit more thermal segregation for PFC. Several districts report that while this process can be used on hot, summer days, it should not be used for PFC mixes on cooler days. A windrow pickup process used in the Yoakum District is shown in [Figure 6](#). Even on an August day in Yoakum, the end of the windrow portion representing the end of the truckload sometimes formed large chunks, which required removal with a front end loader.

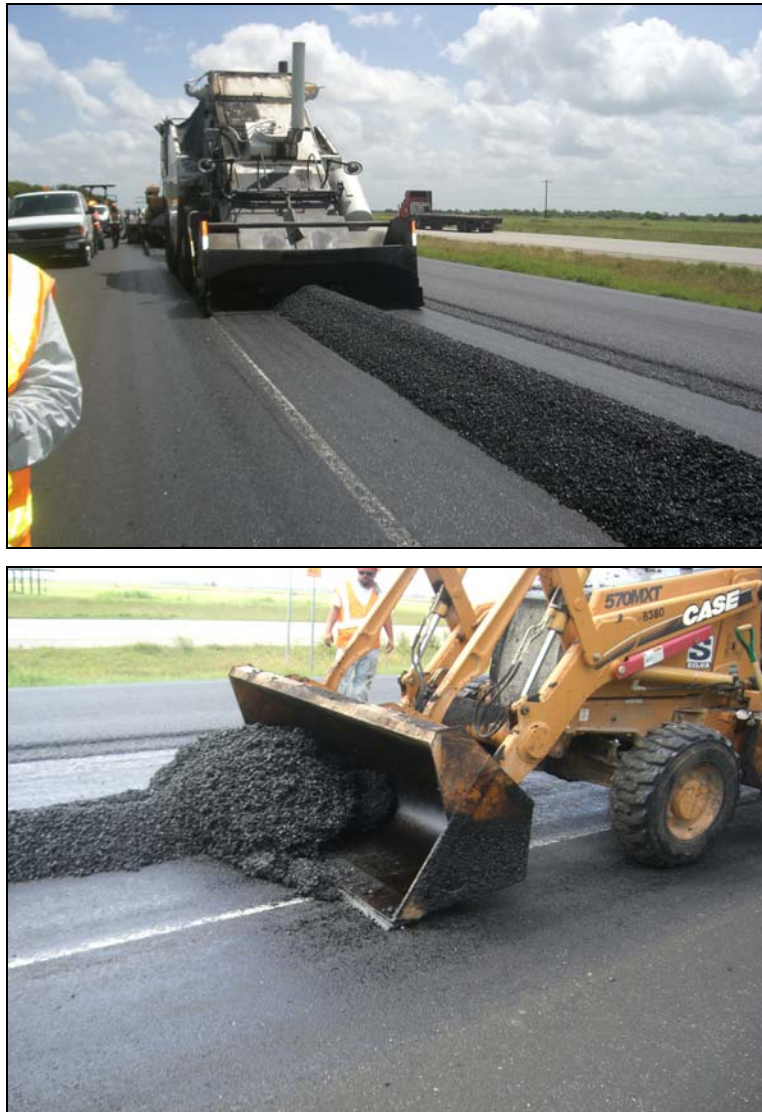


Figure 6. Windrow Pick-Up Process on US 59 in the Yoakum District with Cold Lumps Forming at the End of the Windrow.

Item 342 requires that the mix delivered to the paver not drop below 280°F and thermal profiles are required for each subplot. The Austin District personnel report that they prefer the mix to be at 325°F as it is coming out of the trucks.

Acceptable paving conditions in the United States are commonly defined as a minimum air temperature of 60°F. Although this limit is used by most agencies, there are some exceptions. Florida, for example, requires a minimum air temperature of 45°F (7). TxDOT requires a minimum roadway temperature of 70°F. The British Manual of Contract Documents for Highway Works specifies the maximum wind speed as part of its acceptable paving conditions (12).

Paver Operations

To produce a smooth surface, the paver should advance continuously with minimal stoppages. Districts report that this type of mix will cause a bump in the mat at each location where the paver stops. Any bumps and surface depressions left in the PFC mat are more difficult to correct than in dense graded mixes. When asphalt pavers with extendible screeds are used, researchers recommend auger extensions to avoid irregular distribution of mixture between the center and the edge of the paver (7). The use of a vibratory, hot screed is needed to avoid pulling excessively on the material and diminish the necessity of raking, which can cause areas with lower voids or, more likely, uneven void distribution across the pavement. In addition, raking can generate unsightly surface texture and poor aesthetics, which cannot be rolled out with compaction (6).

Initiation of mixture placement is recommended on the low side of the paving area to avoid accumulation of water (from the rollers or surface water) onto areas to be paved. It is desirable to minimize or even avoid mixture handworking (11, 12).

If the PFC mat is to be placed in the main lanes only, thicker mats may require a taper to join the grade of the existing shoulder. If tapering is required, the Beaumont District recommends the use of a special-type milling machine to mill in the tapers due to the workability difficulties in constructing a taper with the paver for this type of mix. The Yoakum District was able to construct the taper for the notched wedge joint as shown in Figure 7. The smaller roller attached to the paver to roll the taper required a worker to constantly apply a release agent to minimize mixture pickup.



Figure 7. Notched Wedge Joint Construction in PFC.

Handwork on PFC mixtures is difficult to impossible. Experienced districts recommend staying away from crossovers and bridge ends when paving with PFC mixtures and instead paving these areas with dense-graded mix.

Special attention to placement and compaction temperatures for OGFC is required since this mixture is generally constructed using modified binders and may be placed in a thinner mat than dense-graded mixes. Thin layers cool faster and allow less time for compaction. Currently, Japan and some European countries are testing thicker two-layer porous asphalt to provide both noise reduction and safety. In this case, the top layer is about 1 inch thick, and the bottom layer is about 1.5 to 2 inches thick (13). Figure 8 shows a two-layer PFC. The Japanese have developed the Multi-Asphalt Paver (MAP) with capability to simultaneously place both layers of the two-layer system (14).



Figure 8. Double Layer PFC. (15)

In Britain, a nominal thickness of 2 inches is specified to maximize sound attenuation, spray reduction life, water storage capacity, and compaction time. The minimum paver discharge temperature is specified in terms of binder viscosity, with a limit of 5 Pa-s (0.104 lb s/feet²) (11).

MATERIAL COMPACTION AND JOINT CONSTRUCTION

Static steel-wheel rollers are required for the compaction of PFCs. Pneumatic rollers must not be used since their kneading action reduces the mixture drainage capacity by closing surface pores. Minimal compaction is required to seat the mixture without excessive breakage of the aggregate and to provide a smooth surface and uniform texture. Roller drums should be thoroughly moistened with a soap-and-water solution to prevent adhesion. Only water or an approved release agent may be used on rollers, tamps, and other compaction equipment.

Typically, two to four passes (within the adequate range of temperature) with an 8- to 9-ton tandem roller are adequate to complete the compaction process on thin layers. FHWA recommends one or two passes of an 8- to 10-ton static steel wheel roller (10). The Design Manual for Roads and Bridges (Britain) recommends application of at least five passes, but they typically use thicker (~2-inch) layers (11). Rollers heavier than 10 tons should be avoided to minimize aggregate breakage.

Research has shown that the aggregate gradation has a far greater influence on aggregate degradation under compaction than alterations to the level of compaction energy (16). PFC

mixtures experience a greater amount of aggregate degradation after compaction compared to a dense-graded mix. There should be a balance between achieving the needed compaction to ensure durability of the mixture without degrading the aggregate as well as providing a minimal amount of compaction to achieve drainability.

Texas Transportation Institute (TTI) researchers recommend the use of Tex-246-F (Figure 9) to verify that the compacted mixture has adequate permeability (5). The test evaluates the time required to discharge a given volume of water channeled onto the pavement surface through a 6-inch diameter opening. This time corresponds to the water flow value (WFV) and is expressed in seconds.



Figure 9. Test Method Tex-246-F, Field Water Flow Test.

Figure 10 shows how the field water flow values change with each roller pass and how two different mixes (both constructed under Item 342) can behave very differently. To ensure adequate permeability, the field water flow value should not exceed 20 seconds. For the US 290 mixture shown in Figure 10, this water flow value of 20 seconds corresponds to a compaction effort of not more than four passes. For the US 59 mix in Yoakum shown in Figure 10, the field water flow value did not change significantly after the first two passes. Mixture differences are shown in Table 1.

Care should also be exercised to minimize the amount of roller overlap which often occurs in the center of the mat. This results in the center of the mat receiving more compaction than the outside edges and is not a problem for dense-graded mixes. Additional compaction due

to roller overlap in the center of the PFC mat for the US 290 mixture in Austin (Figure 10) could restrict the lateral flow of water through the mix.

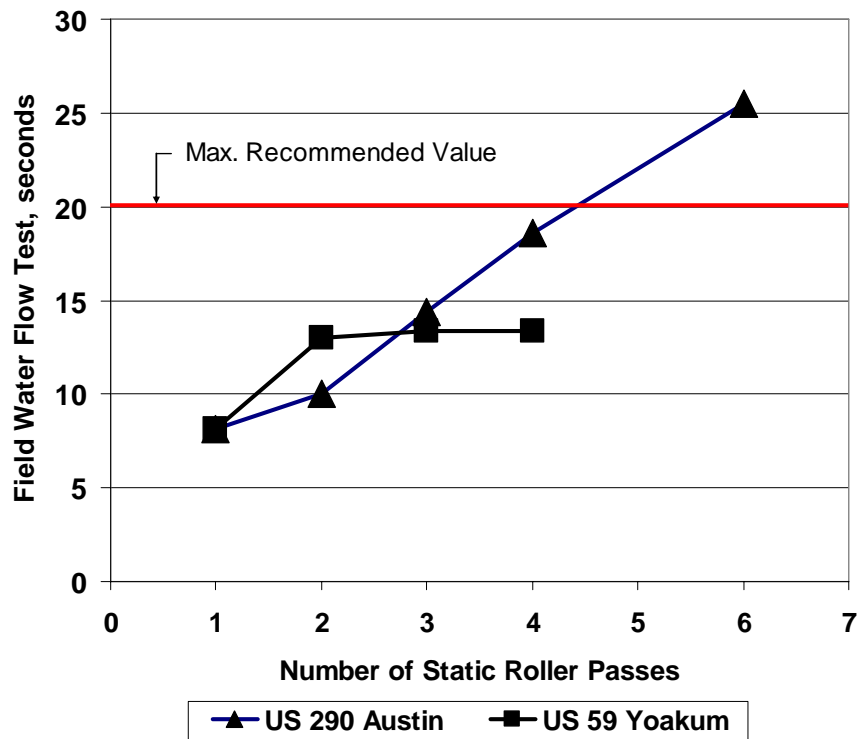


Figure 10. Field Water Flow Value Versus Field Compaction Effort.

Table 1. Mixture Designs Used on US 59 Yoakum and US 290 Austin.

Sieve Size	US 59 Yoakum Mix, % pass	US 290 Austin Mix, % pass
3/4 in	100.0	100.0
1/2 in	84.5	99.7
3/8 in	52.8	75.7
No. 4	6.6	7.9
No. 8	4.2	1.1
No. 200	2.4	0.6
Binder Type and Content	PG 76-22S w/Fiber 6.0%	Asphalt Rubber 8.3%

One of the requirements implemented by the Houston District is that only one roller pass is allowed (i.e., rollers are not permitted to back up). This requires two rollers operating in

tandem to achieve one full coverage of the mat (Figure 11). Water flow values for this pavement after one roller pass was about 10 seconds.

Stopping the roller on the mat for an extended length of time may leave a roller mark.



Figure 11. A Single Roller Pass as Allowed in the Houston District (No Roller Back Up Allowed).

Longitudinal joints should always be located outside the wheel paths. Most districts use a conventional butt joint, though the Yoakum District has successfully constructed the notched wedge joint as shown previously in Figure 7. Longitudinal joints for PFCs should be constructed in much the same manner as for dense-graded mixes. There are four steps to correctly constructing a longitudinal joint:

- (1) Properly compact the unsupported edge of lane 1.
- (2) Properly overlap the mix from lane 2 to lane 1.
- (3) Don't rake the joint.
- (4) Locate rollers at the proper location when compacting the joint.

The edge of the steel wheel drum should extend over the unsupported edge of the lane paved first by 6 inches. This will prevent shear loading which can occur at the edge of the drum and can cause the mix to move transversely. Secondly, when the mix from lane 2 is placed over the top of the compacted mix from lane 1, the mix needs to be high by the amount of compaction that will occur. For dense-graded mixes, this is typically about 0.25 inch per 1 inch thick mat.

For example, to obtain a 1 inch thick compacted mat, the mix should be about 1.25 inches thick prior to compaction. The amount of “roll down” that will occur for a PFC mixture is much less, about 0.1 inches of roll down per inch of compacted mat thickness. There should be very little transverse overlap of the mix from lane 2 to the lane 1, less than 1 inch. No raking should be performed at the joint and is not necessary if the proper vertical and horizontal overlap is achieved. Finally, to compact the joint, the most efficient location is to place the rollers on the hot side of the mat with 6 inches extended over the joint.

Joint adhesives or tack coats are sometimes placed on the longitudinal unsupported mat edge to improve the bond to the subsequent lane at the joint interface of dense-graded mixtures. This practice should be avoided for PFC mixtures since additional binder at the joint interface could reduce the permeability and interfere with the lateral movement of water.

MIXTURE ACCEPTANCE

Even though specified density in the field is not currently required, adequate compaction is necessary since low-density zones are prone to raveling. On the other hand, too much compaction can affect the mixture’s permeability. The practice in most agencies for mixture approval is based on the evaluation of binder content and gradation and the execution of visual inspection of the mixture after compaction to evaluate (qualitatively but not quantitatively) the density, material variability, and segregation. TxDOT accepts the mixture based on aggregate gradation, lab-molded density, binder content, draindown, boil test, and a thermal profile. In addition, the engineer may take samples or cores from suspect areas to determine recovered asphalt properties. Corrective action is also required if there are any surface irregularities such as segregation, rutting, raveling, flushing, fat spots, mat slippage, color, texture, roller marks, tears, gouges, streaks, or uncoated aggregate particles. Essentially, all agencies, including TxDOT, specify a minimum smoothness (7).

In Spain, the acceptance criterion corresponds to the determination of the mean air voids content (for which a maximum difference of 2 percent in comparison with the reference air voids content is required.) In England, a specified hydraulic conductivity of the material is required and is evaluated in the field before any traffic is permitted.

CHAPTER 3.0 MAINTENANCE

PFC mixtures may exhibit the following distress modes (3):

- shear failures in high stress areas,
- cracking due to fatigue,
- cracking due to reflection from below,
- raveling due to oxidation and hardening of the binder,
- raveling due to softened binder from oil and fuel drippings,
- raveling due to lack of compaction or low asphalt content,
- delamination due to improper tack coat application,
- clogging of voids from mud or sand causing loss of permeability (a clogged PFC still drains better than a dense graded mix), and
- rich and dry spots due to draindown of binder during transportation and placement.

TxDOT PFC mixtures that are designed and placed under Item 342 are relatively new (less than 5 years old) and, thus far, have performed well with little to no maintenance required. No rutting has been observed on any of the in-place mixes throughout this research project, and many of the PFCs are under very heavy traffic. Some minimal cracking has been observed, which appears to be a reflection of underlying cracks. Longer-term performance concerns for PFCs are with regards to raveling and delamination, though there is little evidence of these failure modes in the current mixes to date. One of the original Item 342 PFCs was placed on IH-35 just north of San Antonio. This mixture started to exhibit some isolated performance problems at about 4 years of age. Small isolated areas in the wheel paths were exhibiting signs of delamination or raveling or both.

TTI took some cores from this roadway in 2007, and these cores are shown in [Figure 12](#). This mix was constructed with 50 percent sandstone, 50 percent limestone, and an asphalt rubber binder. The pictures in [Figure 12](#) show the bottom of the PFC layer. There was no seal coat under the PFC. The failures on this PFC were occurring in the wheel paths. Note the underside of the core taken from the wheel path in [Figure 12](#). The tack coat no longer seems to be functioning, and in fact, the cleanliness of the aggregate surfaces indicates the asphalt binder from the mix as well as the tack may have stripped from the aggregate surfaces.

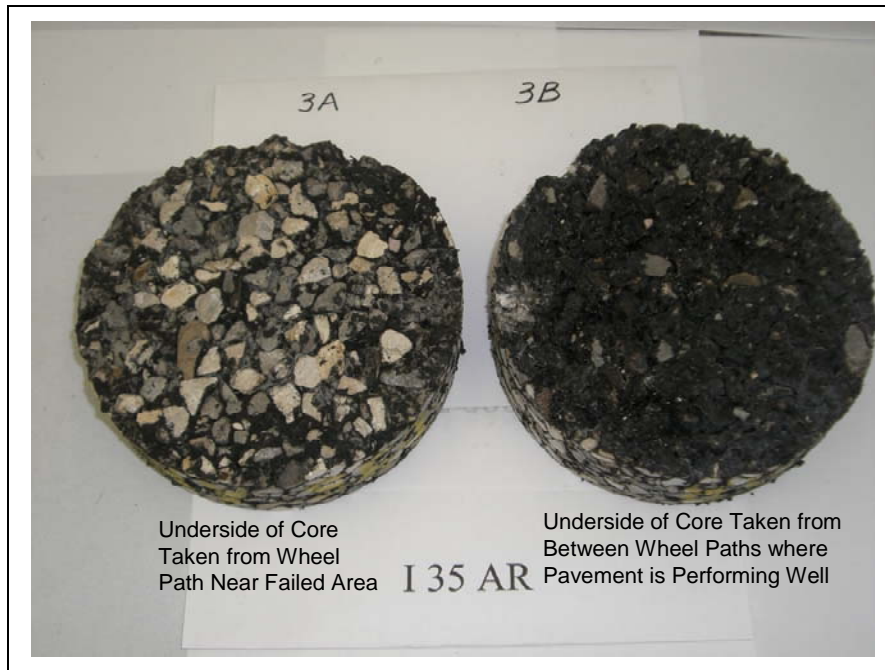


Figure 12. Cores Taken from Distressed PFC on IH-35 in San Antonio.

Because these were small isolated areas, the maintenance section was able to repair the mix with dense graded patching materials without severely impacting the drainage characteristics of the mix.

CORRECTIVE MAINTENANCE

Mill and inlay using PFC was recommended in Oregon to repair PFC when the quantities of material were enough to justify these activities. FHWA advises one to consider the area and the drainage continuity (10). Thus, when the area to be repaired is small and the flow around the patch can be ensured, dense-graded mix is recommended for patching. Otherwise, the zone should be repaired by using PFC mixture. In 2000, the use of dense graded mix to repair delaminated areas and potholes was indicated by all states in the United States that reported the utilization of PFC. Only the Wyoming DOT reported crack filling, and according to their experience, drainage problems can result from crack sealing, since water flow inside the material is diminished (7).

In Britain, the use of PFC or open-graded macadam is recommended to repair both small and large potholes. The use of dense bitumen macadam is permitted, if necessary, but its

replacement by permeable mixture is recommended. Finally, the application of hot-rolled asphalt is limited for repairing small areas (i.e., 18 inch x 18 inch) (11).

To diminish the wheel impact on the patch joint and facilitate the flow of water around a dense graded patch, rotation of the patch to 45 degrees to provide a diamond shape is recommended. Alternatively, the execution of machine patch, blade patch, or screed patch may be used (17).

SURFACE MAINTENANCE

According to a survey conducted as part of the National Cooperative Highway Research Program (NCHRP) Synthesis 284, there are no reports in the United States on the application of major maintenance for PFC. From 17 states that reported their use, only New Mexico, Wyoming, South Carolina, and Oregon employ fog seals to perform preventive maintenance. Although quantitative information about the significance of these treatments is not available, it is expected that fog seals extend the life of porous mixtures since they provide a small film of unaged asphalt at the surface (17). FHWA recommends fog seal application in two passes (at a rate of 0.05 gal/yd² for each pass) using a 50 percent dilution of asphalt emulsion without any rejuvenating agents (10).

Research in Oregon regarding permeability reduction and changes in pavement friction on certain PFC pavements generated by fog seals concluded that the mixtures still retain porosity and keep the rough texture related to its capability to reduce the potential for hydroplaning (17). However, quantitative conclusions regarding the changes in these parameters are not included. A decrease in pavement friction was noticed immediately after fog seal application, but during the first month, it increased considerably by traffic action.

Snowplow blade abrasion has considerable effects on the durability of traffic markings on PFC. Thermoplastic markings or even some fragments of mixture impregnated with thermoplastic can be displaced when steel snowplow blades are used for winter maintenance. Field trials in Rhode Island showed the lack of durability of the permanent inlaid traffic marking tape on modified PFC under such conditions. Therefore, Rhode Island recommended suspension of its use until corrections can be implemented to improve its durability (18).

Rhode Island further reported that recessed thermoplastic traffic markings proved cost effective in comparison with non-recessed thermoplastic markings. Although recessed

thermoplastic traffic markings showed lower snowplow blade damage, fully and semi-recessed markings installed in a tangent highway test section failed to maintain the recommended minimum retroreflectivity in wet night conditions. This result was associated with the effect of the water film present in the tangent section but was irrelevant in the super-elevated curved test section included in the research (18).

Highway agencies in British Columbia, South Carolina, and Maryland reported that thermoplastic marking material was the most appropriate for PFC applications (7). The British limit the use of pavement markings with thermoplastic materials to certain directional signs and arrows, considering that in PFC the marking material has more opportunity to flow downward into the mixture (11). Although higher demand of marking material in PFC (due to higher porosity) was reported by some agencies in the United States (e.g., Ohio, New York, and Oregon), there were no specific recommendations regarding materials for traffic marking (7).

Cleaning of PFC in the United States is not common practice. This approach indicates that local agencies accept that PFC functionality can be maintained due to its auto-cleaning capacity created in highways with relative high speed and high volumes of traffic by the suction generated by tires rolling on the PFC (19). High-pressure washing is currently quite expensive and of questionable value. Current maintenance activities in Denmark include cleaning of the voids by high-pressure water and air suction twice a year as a strategy that combines the construction of two-layer drainage asphalt and cleaning in order to maintain porosity during the pavement lifetime (20). In general, European practice limits placing of PFC on highways with speeds higher than 30 mph to help in keeping the surface clean (13). On the other hand, Japan is applying the “function maintenance” concept that comprises more frequent cleaning operations with only partial debris removal during each cleaning (14).

WINTER MAINTENANCE

In general, PFC mixtures exhibit lower thermal conductivity and reduced heat capacity compared with dense-graded hot mix (11). Elevated air voids contents in PFC reduce the flow rate of heat through the material. In fact, the thermal conductivity of PFC can be 40 to 70 percent the magnitude of that for dense-graded mix, making PFC operate as an “insulating course” at the surface (7).

As a result of these thermal properties, the surface of a PFC can exhibit temperatures 2 to 4°F lower than the surface temperature of adjacent dense-graded mix, producing earlier and more frequent frost and ice formation (7, 9). Longer periods under such conditions, compared with dense graded mixes, are thus expected. The occurrence of this phenomenon has been identified in Europe (7, 21), in the United States and specifically in Texas. Thus, the time to reach adequate pavement friction values after ice formation has occurred is longer in porous pavement (7). In fact, formation of black ice and extended frozen periods are currently considered the main problems associated with PFC maintenance in the United States.

Consequently, PFC requires specific winter maintenance practices. For example, in addition to conventional practices for winter maintenance, the use of pavement condition sensors, meteorological instrumentation, and connecting hardware and software is suggested to monitor the road system and support the decision process involving when and how to treat a PFC surface (19).

More salt (or deicing agents) and more frequent applications than on dense graded mixes are required to perform winter maintenance on PFC (7, 11, 17, 22). In Texas, deicing agents are currently considered the most effective winter treatment, followed by liquid deicer agents and sand. However, the FHWA recommends developing snow and ice control using chemical deicers and plowing and avoiding the use of abrasive materials to improve traction (10). Spreading of sand to enhance friction and hasten deicing contributes to the clogging of voids, causing a decrease in drainage and noise reduction capabilities, which are considered two of the main PFC advantages (19).

Since the deicer can flow into a PFC instead of remaining at the surface, Oregon DOT has suggested research on organic deicers with higher viscosity and electrostatic charge technology (similar to that employed in emulsified asphalt) to improve bonding of deicers on the surface (17).

Intensive application of liquid deicing salts has allowed Belgium to obtain similar conditions between dense and porous mixtures subjected to snowy weather. Further, higher frequency of application and 25 percent more liquid salting are reported in The Netherlands to address winter maintenance difficulties in PFC (23). Furthermore, the use of liquid chloride solutions was reported in the cold Alpine regions of Italy, Austria, and Switzerland as more effective than the use of solid salt (19). On the contrary, a Japanese study concluded that

fundamental modifications are not required to practice winter maintenance in PFC surfaces, since considerable differences between these mixtures and dense-graded mixes were not found (24).

Britain practices preventive salting just before snowfall and more frequent application of salt in comparison with dense graded mix (11). They recommend increasing the amount of salt applied on dense graded sections that are adjacent to PFC segments. This recommendation is due to the reduction in the transfer of salt from the PFC to the dense-graded mix and the differences in response of each material. Additionally, they propose prompt plowing of snow using plows fitted with rubber edges on the blades (to prevent surface damage). Finally, greater control in the homogeneous supply of deicing chemical is required in PFC, as the traffic has minimal contribution in its distribution over the surface (19).

In Texas, severe weather events are generally confined to the northern section of the state. It is in these areas that district personnel must prepare for winter maintenance strategies for PFC pavements (25).

As is indicated from the literature and the current practice of TxDOT districts, anti-icing procedures may produce the best result to combat black ice, freezing rain, and light snow events (25). Anti-icing procedures involve a combination of liquid, dry solid, and prewetted chemicals applied at the appropriate times, taking into consideration temperature, the amount of moisture and traffic conditions. De-icing procedures should be reserved for events in which ice and snow have already bonded. These procedures generally require more materials and do not maintain safe road conditions as well as anti-icing procedures.

Sand should only be used in emergency situations where quick friction is needed, for instance, during a surprise ice or snow event (25). Use of sand on these pavements may cause clogging to occur, which reduces the draining benefits of PFC. The use of other materials may be used to generate the needed friction.

Table 2 shows a plan for anti-icing and de-icing operations suggested by the FHWA in a black ice event (26).

Table 2. Weather Event: Frost or Black Ice (25, 26).

Pavement Temp. Range and Trend and Relation to Dew Point	Traffic Condition	Initial Operation			Subsequent Operations			Comments
		Maint. action	Dry chemical spread rate, kg/lane-km (lb/lane-mi)		Maint. action	Dry chemical spread rate, kg/lane-km (lb/lane-mi)		
			liquid	solid or prewetted solid		liquid	solid or prewetted solid	
Above 0°C (32°F) , steady or rising	Any level	None, see comments			None, see comments			Monitor pavement temperature closely; begin treatment if temperature starts to fall to 0°C (32°F) or below and is at or below dew point
-2 to 2°C (28 to 35°F) , remaining in range or falling to 0°C (32°F) or below, <i>and</i> equal to or below dew point	Traffic rate less than 100 vehicles per h	Apply prewetted solid chemical		7-18 (25-65)	Reapply prewetted solid chemical as needed		7-18 (25-65)	1) Monitor pavement closely; if pavement becomes wet or if thin ice forms, reapply chemical at higher indicated rate 2) Do not apply liquid chemical on ice so thick that the pavement can not be seen
	Traffic rate greater than 100 vehicles per h	Apply liquid or prewetted solid chemical	7-18 (25-65)	7-18 (25-65)	Reapply liquid or prewetted solid chemical as needed	11-32 (40-115)	7-18 (25-65)	
-7 to -2°C (20 to 28°F) , remaining in range, <i>and</i> equal to or below dew point	Any level	Apply liquid or prewetted solid chemical	18-36 (65-130)	18-36 (65-130)	Reapply liquid or prewetted solid chemical when needed	18-36 (65-130)	18-36 (65-130)	1) Monitor pavement closely; if thin ice forms, reapply chemical at higher indicated rate 2) Applications will need to be more frequent at higher levels of condensation; if traffic volumes are not enough to disperse condensation, it may be necessary to increase frequency 3) It is not advisable to apply a liquid chemical at the indicated spread rate when the pavement temperature drops below -5°C (23°F)
-10 to -7°C (15 to 20°F) , remaining in range, <i>and</i> equal to or below dew point	Any level	Apply prewetted solid chemical		36-55 (130-200)	Reapply prewetted solid chemical when needed		36-55 (130-200)	1) Monitor pavement closely; if thin ice forms, reapply chemical at higher indicated rate 2) Applications will need to be more frequent at higher levels of condensation; if traffic volumes are not enough to disperse condensation, it may be necessary to increase frequency
Below -10°C (15°F) , steady or falling	Any level	Apply abrasives			Apply abrasives as needed			It is not recommended that chemicals be applied in this temperature range

Notes:

Timing: (1) Conduct initial operation in advance of freezing. Apply liquid chemical up to 3 hrs in advance. Use longer advance times in this range to effect drying when traffic volume is low. Apply prewetted solid 1 to 2 hrs in advance. (2) in the absence of precipitation, liquid chemical at 75 lb/lane-mi has been successful in preventing bridge deck icing when placed up to 4 days before freezing on higher volume roads and 7 days before on lower volume roads.

REHABILITATION

An ideal set of technical actions for major rehabilitation of PFC has been defined by some DOTs (e.g., Florida and Georgia) as mill, recycle, and inlay. The same approach has been recommended in Oregon and reported as the favored approach in The Netherlands (17). When inlaying PFC, one must avoid creating an impermeable vertical wall at the lower side of the inlay and, thus, the potential for ponding water. In the absence of raveling or delamination demanding rehabilitation, once the PFC has lost its functionality (i.e., permeability and noise reduction) by clogging, its service might still be permitted since it essentially behaves as a dense-graded mix with low permeability (7).

General recommendations and actual practices for rehabilitation of PFC in the United States include milling and replacing of existing PFC with new PFC or any other asphalt mixture (7, 9, 10). Direct placement of new dense-graded mix over porous mixture is not recommended because life of the new layer can be diminished by water accumulation inside the PFC. Experimental reports from The Netherlands showed that recycled PFC kept approximately the same permeability, and its durability (evaluated by the Cantabro test) is similar to that of a new mixture (7).

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