Noise Reducing Porous Asphalt Pavement

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ABSTRACT: New generation permeable friction course (PFC) technology has become attractive since PFC reduces highway noise levels and lessens the water spray behind vehicles during rain events. A PFC test section was installed in 2005 on a new alignment, 4-lane section of US-50 approximately 8 km east of Garden City, Kansas, USA. The hot-mix asphalt (HMA) mixture was gap graded which resulted in a mat with 20% air voids that would allow rainwater to run through it to the edge of the roadway. The PFC mixture used a performance graded (PG) 76-28 binder modified with tire rubber. Pass-by sound level samples and interior sound level samples were collected right after construction with a Larson-Davis Model 720 Type 2 Sound Level Meter. Tests were done on two test sections (PFC and conventional HMA) from a Ford Taurus and from a dump truck at 88 km/hr speed. On each test section, sound levels were collected at two distances: 7.6 m and 18.2 m from the centerline of the roadway. Interior noise level samples were measured in the car when its speed reached 88 km/hr for approximately 0.8 km. The surface friction properties were periodically evaluated with an ASTM skid trailer. The noise evaluation results show that for both car and truck, PFC was found to generate significantly lower sound levels than the conventional HMA (Superpave mixture). Greater noise reduction was observed for the truck.

KEY WORDS: Permeable friction course, porous asphalt pavement, noise reducing pavement, open graded friction course, hot-mix asphalt.

1 INTRODUCTION

Open-graded friction courses (OGFC) are gap-graded hot-mix asphalt (HMA) mixtures with a high amount of interconnected air voids so that water can drain through and over the surface of this mixture (Roberts et al. 1996). Removal of water from the pavement surface reduces the hydroplaning potential and improves overall skid resistance. This mixture also has noise reduction capacity. These two properties are the primary advantages and reasons for use of OGFC during the last few decades in Europe and the United States.

Although an OGFC mixture is produced at the same plant as the dense graded HMA, the primray difference between the two lies in the gradation of the aggregates. Rubberized asphalt is often used in the production of OGFC to improve the ability of the asphalt binder to hold the aggregates in place. Although the void content of OGFC is very high, the asphalt film thickness is typically greater than that for the dense-graded HMA. Some of the mix design procedures for the OGFC mixtures would give the asphalt content necessary to provide some specified minimum film thickness (Roberts et al. 1996).

An OGFC surface has been shown to improve skid resistance, especially in wet weather. Howeever, its use has been limited in some states due to performance problems. A number of states reported stripping in the layer directly below the OGFC layer. This problem has been largely resloved through the use of antistripping agents. Some other states including Kansas reported that use of sand or cinder for winter maintenance operations tends to clog the OGFC layer limiting its effectiveness (Kandhal et al. 1977).

In the early ’00s, the National Center for Asphalt Technology (NCAT) proposed a mixture design method for a new-generation of OGFC (Watson et al. 2003). These proposed mixtures are open-graded with a minimum air voids content of 18 percent, and in general, contain fibers and polymer-modified binders. A variation of this mixture, termed porous friction courses (PFC), has been adopted in Texas and defined in TxDOT Specifications, Item 342, as a surface course of a compacted permeable mixture of aggregate, asphalt binder, and additives mixed hot in a mixing plant (Alvarez et al. 2006). The experimental PFC section in Kansas followed this Texas specification very closely. The obejctives of using this permeable friction course (PFC) technology in Kansas were to reduce highway noise levels and to lessen the water spray behind vehicles during rain events.

2 PROJECT DESCRIPTIONS

The experimental PFC project was built in 2005 on a new alignment, 4-lane section of US-50 approximately 8 km east of Garden City, Kansas (population: 27,000). There is approximately 0.8 km of PFC in the EB and WB direction (all four lanes). The PFC layer was placed across the shoulder and daylighted in the graded ditch and median.

The 2002 Annual Average Daily Traffic (AADT) on this section was 4,920. The design 80-kN Equivalent Single Axle Loads (ESALs) was 1,075 for 2002 and 1,295 in 2012. The climate of this area is subhumid to semiarid type with an annual rainfall of 483 mm. The average mean annual temperature at Garden City is 12.6 ^{o}C. The highest temperatures occur during the three summer months, the monthly mean being 23 ^{o}C in June, 25.9 ^{o}C in July and 25.3 ^{o}C. in August. January and December are generally the coldest months, the mean monthly temperature being -0.6 ^{o}C in January and 0 ^{o}C in December. The annual snowfall amounts to about 584 mm.

The soil in the project is a clay with low plasticity (CL). The average Liquid limit and Plasticity Index are 27 and 9, respectively. The plasticity index varied from a low of 1 to a high of 18.

2.1 Pavement Cross Sections

The pavement cross-section is a full-depth asphalt pavement built on a fly ash-treated subgrade (FATSG). The original cross section consisted of a 40-mm bituminous surface (9.5 mm nominal maximum aggregate size (NMAS) Superpave mix with PG 70-28 binder), a 60-mm bituminous base (19-mm NMAS Superpave mix with PG 70-28 binder), a 280-mm bituminous base (19-mm NMAS Superpave mix with PG 64-22 binder) and a 150-mm FATSG. On the experimental PFC section, the 40-mm bituminous surface was paved with the PFC mixture instead of the 9.5-mm NMAS Superpave mix with PG 76-28 binder.

The pavement has a cross slope of 1.6% in the travelled lane and 4.2% in the full-width shoulder. As mentioned earlier, the PFC was extended across the shoulder to have a daylighted effect.

3 PFC MIXTURE DESIGN

The PFC mixture design was done following the Texas specifications for Porous Friction Course (TxDOT Test Method Tex-204-F, Section 7-Part V item 342) (TxDOT 2004), except no Micro-Deval test was done for aggregate characterization. Instead the Los Angeles Abrasion test was used. The aggregates in PFC were crushed gravels imported from Colorado. Two different aggregates were used – a 19-mm rock (40%) and a 12.5-mm chip (60%). These aggregates came from the same sources as the Superpave mixtures in the project. The gradation is shown in Figure 1. The figure also plots the limits of the gradation required by the Texas specification. The aggregates met the requirements for coarse aggregate angularity (100/97), sand equivalent (45 min.), LA abrasion (30% max.), flat and elongated particles (10% max.). No natural sand was allowed in the mix. The Kansas mixture used a tire rubber modified PG 76-28 binder. A liquid anti-stripping agent (0.5%) and a fiber additive (0.3% by weight of aggregate) were also used. Table 1 shows the specifications of the PG 76-28 binder with the tire rubber modifier. Verification tests by KDOT showed that the supplied binder met all the required criteria.

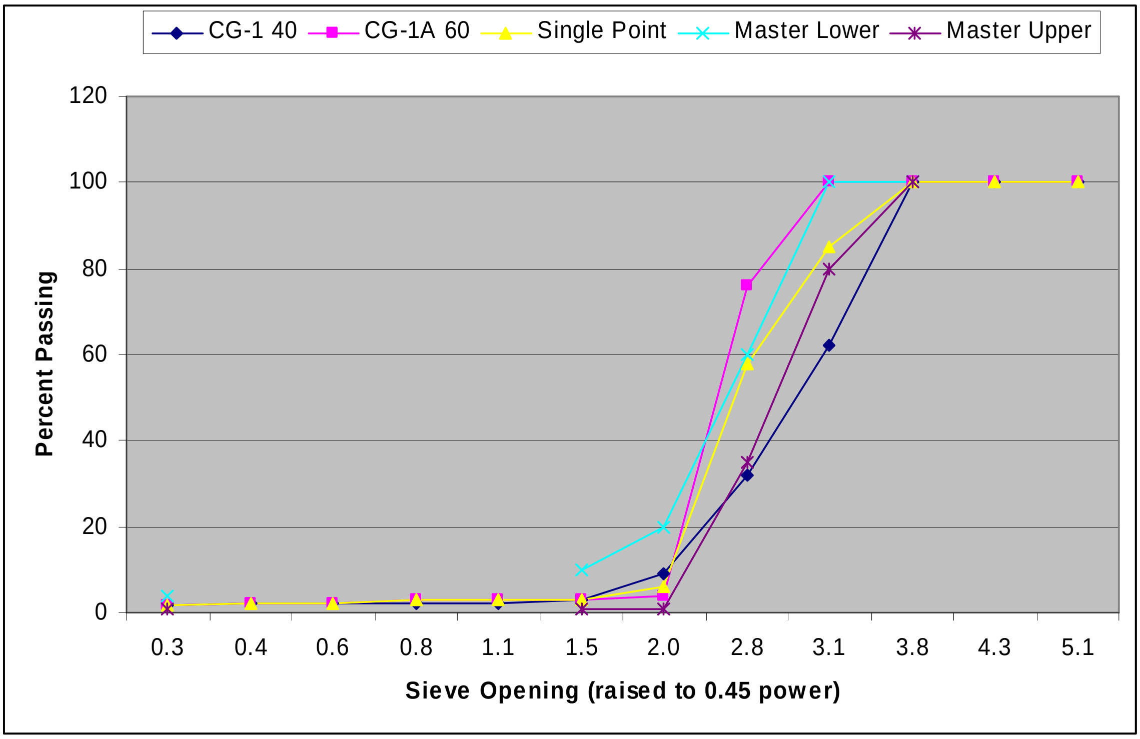

Figure 1: Gradation of the Aggregates in Kansas PFC

Following selection of materials, two replicate specimens (150-mm diameter by 115-mm height) at each of the three binder contents (5.5%, 6.0% and 6.5%) were mixed, short-term aged in an oven for 2 hours at the compaction temperature, and compacted in the Superpave Gyratory Compactor (SGC) using 50 gyrations. An optimum binder content of 6.0% was then selected based on the target density of 80%. At this asphalt content, the air void content was 20%. Next specimens at the selected optimum binder content were fabricated for an evaluation of draindown (Tex-235-F), and moisture susceptibility (Tex-530-C). The optimum mixture had a draindown of 0.04% (0.2% maximum allowed). The draindown is defined as the ratio of: (1) 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 (2) the original specimen weight. The moisture susceptibility of the optimum mixture was determined by boiling the loose mixture in water for 10 minutes and visually evaluating the percentage of stripping immediately and after 24 hours. No aging test of the binder was done. The design was verified by the bituminous research unit of the Kansas Department of Transportation (KDOT). Table 2 shows the comparison. Hamburg rut tests were also done on the samples of PFC mixtures. The tests were ran at 40^{o}C. The samples carried 20,000 wheel repetitions with only 3 mm rut depth.

Table 1: Specifications for the tire rubber modfied PG 76-28 binder

Properties	**Specification**		**Test Method**
	Minimum	**Maximum**	
Original			
Flash Point Temp. T48,^{o}C	230		ASTM D 3143
Softening Point, ^{o}C	56		ASTM D 36
Solubility in Trichloroethylene,%	98.5		ASTM D 2042
Rotational Viscosity, Pas (#27 Spindle @135 ^{o}C)	3.0		AASHTO MP-1
Elastic Recovery, 10^{o}C, 5 cm/min.	55		ASTM D 6084
G*/Sinδ @76^{o}C (10 rad/sec,kPa)	1.00		ASHTO MP-1
RTFO Aging			
G*/Sinδ @76^{o}C (10 rad/sec,kPa)	2.200		ASHTO MP-1
PAV Aging			
G*/Sinδ @25^{o}C (10 rad/sec,kPa)		5,000	ASHTO MP-1
Creep Stiffness, MPa, S, -18^{o}C@ 60sec		300	ASHTO MP-1
M-Value,-18^{o}C@ 60sec	0.300		ASHTO MP-1

Table 2: PFC Mix Design Verification

TEST	KDOT	Contractor	COMMENTS
G_{sb}	2.583	2.579	KT-6,Proc I
G_{mm}	2.418	2.377	KT-39
G_{mb}	1.936 avg.	1.904	KT-15,Proc II
Air Voids	19.9 avg.	20.0	KT-15,Proc II
Draindown @163°C	0.04	0.04	KT-63
Draindown @178°C	0.14	*	KT-63
Boil Test	0%	0%	Tex-530-C
Washed Gradation			Single Point/Limits
19 mm	0	0	0/0
12 mm	14	15	15/0-20
9.5 mm	41	42	42/40-65
4.75 mm	93	94	94/80-99
2.36 mm	96	97	97/90-99
1.18 mm	96	97	97/
0.6 mm	97	97	97/
0.3 mm	97	98	98/
0.15 mm	97	98	98/
0.074 mm	97.8	98.2	98.2/

4 CONSTRUCTION

The construction was done following the Texas specifications. A trial batch was produced and the normal test strip procedure in Kansas was done for finding compaction pattern. Paving was done with a conventional asphalt paver (RoadTec with rubber tires). A material transfer vehicle (RoadTec 2500) was also used. Segregation profiling was done using a nuclear gage. The PFC samples were collected from the paver hopper in order to avoid damaging the newly paved surface.

Compaction was done with the steel-wheeled rollers in a static mode. Breakdown compaction was done with two steel-wheeled rollers, and each one made two passes. The finishing roller made only one pass.

5 PERFORMANCE

In addition to visual observations of pavement surface condition, an assessment of snow and ice control has been done to date. The PFC winter weather treatments using anti-icing pre-treatment methods were the same as those on the adjacent HMA pavement. No adverse effect was noticed. The surface friction and noise tests were also conducted.

5.1 Noise Test

Pass-by sound level and interior sound level samples were collected immediately after construction with a Larson-Davis Model 720 Type 2 Sound Level Meter. The meter was operated in the "A" weighted mode set to fast response, and calibrated with a Larson Davis model CAL 150. Samples were collected on two test sections (PFC and conventional HMA) from a Ford Taurus and from a dump truck at 88 km/hr speed. Pass-by sound levels were measured for five trucks and five cars for each pavement test sections (PFC and conventional HMA). Sound from the truck and car were measured five times each. However, average of consecutive three same readings out of five measurements were used. On each test section, sound levels were collected at two distances: 7.6 m and 18.2 m from the centerline of the roadway. The stationing at both distances was the same. Interior noise levels were measured in the car when its speed reached 88 km/hr for approximately 0.8 km. Table 3 shows the results. The results show that for car, pass-by sound level samples at 7.6 m indicated that noise level on the PFC section was three decibels lower than that on the dense-graded hot-mix asphalt section. At 18.2-m offset, the PFC noise level was five decibels lower than that of the dense graded section. For truck, the noise levels at 7.6-m and 18.2-m offset on PFC were six and five decibels lower, respectively, than those on the dense graded section. However, the car interior measurements on both sections are comparable; to the human ear, the interior noise in the car seemed lower. It is clear that PFC is quite effective in reducing road noise.

Table 3: Summary of Noise Test Results at 88 km/hr

Sample Type	Distance to Center line (m)	Surface Type			
		PFC		Dense-Graded HMA	
		Avg. L_{max} dB- Car	Avg. L_{max} dB-Truck	Avg. L_{max} dB- Car	Avg. L_{max} dB-Truck
Exterior	7.6	76	85	79	91
	18.2	66	79	71	84
Interior	-	68		67	

5.2 Surface Friction Test

Since the surface friction properties of the PFC section were of interest to KDOT, it has been evaluated continuously since construction. The friction properties were measured using an ASTM skid trailer at both 64 km/hr and 88 km/hr. Table 4 shows the test results. The average skid number for the PFC section was low immediately after construction compared to the dense graded asphalt. However, subsequent measurements indicate that the skid numbers for both surface types are comparable.

Table 4: Summary of Surface Friction Test Results

Survey Date	Surface Type			
	PFC		Dense Graded HMA	
	64 km/hr	88 km/hr	64 km/hr	88 km/hr
November 2005	39	-	59	-
August 2006	54	51	59	52
June 2007	56	52	58	54
July 2008	58	54	58	54
June 2009	59	55	63	58

5.3 Verification of In-Situ Air Voids

Since obtaining design air voids for this mixture is essential for proper performance of this mix, the air voids were analyzed during preproduction and construction. Table 5 shows the results. The obtained air voids ranged from 16.97% to 19.55%. Thus target air voids were obtained easily in the field.

Table 5: Summary of Air Voids Analysis

Sample Type	Sample ID/Station	Bulk Sp. Gravity	Theo. Max. Sp. Gravity	Air Voids (%)	Density (kg/m^3)	Nuclear Gage Density (kg/ m^3)
Preproduction	PP-A	1.991	2.410	17.4	1985	-
	PP-B	2.001	2.410	16.97	1995	-
	PP-C	1.975	2.410	18.05	1969	-
Roadway	12+850	1.897	2.358	19.55	1891.5	1909.5
	12+660	1.897	2.358	19.55	1890.5	1985.5
	12+350	1.935	2.358	17.93	1929.5	1970

6 CONSCLUSIONS

1. The PFC mixture was successfully designed using a tire rubber-modified PG binder, fibers, and aggregates used in the Superpave mixture design.
2. The PFC mixture production and paving were done using conventional plant and pavers, respectively. Compaction was done with static, steel-wheeled rollers. The volumetric test results showed that the intended air voids were obtained on the PFC section.
3. The skid numbers immediately after construction was lower for the PFC section compared to the conventional section. However, after a couple of months, the skid numbers on both surface types were comparable.
4. The noise test results show that for cars, noise level on the PFC section was three to five decibels lower than that on the dense-graded hot-mix asphalt section depending on the offset location of testing. For trucks, the noise level was five to six decibels lower than those on the dense graded section. However, the car interior measurements on both sections were comparable.

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