To Find Optimum Gradation by Evaluation of Volumetric and Performance Characteristic of Open Graded Friction Courses

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Abstract : Permeable friction course (PFC) mixtures constitute one of the best options for surface paving, since they offer advantages as compared to conventional pavement in terms of safety, economy, and environment. However, mix design and evaluation of PFC mixtures still require improvement and standardization to further promote the reliable use of these mixtures. This an extensive literature review focused on the basic aspects integrated in the mix design and evaluation of PFC mixtures. Although substantial advances related to these topics were reported since implementation of PFC mixtures in the 1990's, there is still a need for integration of several of these advances in an improved mix design procedure. The review also identifies areas that require additional research, including the optimization of the balance between mixture functionality and durability and replacement of the indirect assessment of these important aspects.

Keywords: PFC, Safety System

1. Introduction

Porous friction courses (PFCs) are typical open-graded asphaltic mixes, composed of relatively uniformly-graded aggregate and asphalt cement or modified binders, and are mainly used to serve as drainage layers, either at the pavement surface or within the pavement structure [4].

A permeable friction course PFC is an alternative to traditional hot mix asphalt and is produced by eliminating the fine aggregate from the asphalt mix. A sacrificial layer of porous asphalt approximately 50 mm thick is placed as an overlay on top of an existing conventional concrete or asphalt surface. The void space in a PFC overlay layer generally is 18–22%[9]

Pavements surfaced with open-graded asphaltic mixes were found to improve wet weather skid-resistance, minimize hydroplaning, reduce splash and spray, improve night visibility during wet weather conditions, lower pavement noise level, improve pavement marking visibility [1][2][4][8][22].PP have been installed more frequently for storm water management[8], increased root and shoot extension and biomass of seedlings relative to impervious pavements[5]. They are also facilitate groundwater and interflow recharge and mitigate temperature increases [15], reduce urban heat island effect [16].

The porous structure of PFC also may act as a filter of the storm water. Runoff enters the pores in the overlay surface and is diverted toward the shoulder by the underlying conventional pavement. Pollutants in the runoff can be filtered out as the water flows through the pores, especially suspended solids and other pollutants associated with particles. Filtering occurs when pollutants become attached to the PFC matrix by straining, collision, and other processes. Material that accumulates in the pore spaces of PFC is difficult to transport and may be trapped permanently [9].

It minimizes the negative impacts of the development by reducing the volume and flow intensity of surface runoff, removing pollutants, recharging natural groundwater by infiltration, and reducing the risk of downstream flooding [12][18].

The various terminologies used include open-graded asphalt (OGA), porous asphalt (PA), open-graded friction course (OGFC), and porous friction course (PFC) [4]. In the United States permeable friction course (PFC) mixtures are also termed new generation open-graded friction course (N-OGFC) mixtures, and similar European mixtures are identified as Porous Asphalt (PA) [1].

Apart from their conventional use in parking lot [6], countries like the United States of America, Japan, United Kingdom, Malaysia, Australia, New Zealand, and South Africa, open-graded mixes are in use as surface layers over high-speed and heavily trafficked highway pavements. These are also recommended for surfacing runway pavements [4].

Like any structure porous pavement also have some limitation associated with it. The US Environmental Protection Agency (USE-PA) (1999) recommends that porous pavements only be used on soils with low clay content(<30%), in areas that receive light traffic, that have relatively flat slope(<5%), that have deep permeable soils located away from drinking water sources, and with at least a 4-ft clearance between the pavement and underlying bedrock or water table[8].

The greater amounts of salt must be applied because the pavement freezes faster than conventional pavements due to its higher air void content [8]. Clogging of the PFC pore space can result in a significant reduction in drainage potential [13]. Typical clogging agents include fine particles such as dust, tyre rubber and local residual soils deposited from dirty wheels and heavy vehicles carrying earth dirt [17].

Use of PFC mixtures is guaranteed based on the advantages that these mixtures offer, as compared to conventional dense-graded HMA mixtures, in terms of safety, economy, and the environment [23]. The specific characteristics of PFC mixtures and the relationship between the AV characteristics and both mixture design and performance encourage further examination of the mixture internal structure [22].

2. Material

The first step in the mix design process is to select materials suitable for the OGFC. Materials include aggregates, asphalt, and additives. The appropriate selection leads half done.

2.1 Aggregate

Crushed stone aggregates are the major constituents of PFC mixes [4]. Table 1 shows the physical properties of aggregates tested in accordance with the requirements of the ASTM D7064 [26].

Table 1- *Physical properties of aggregates*

Coarse aggregates Flat and elongated particles , %	Max. 10(with ratio of 5:1 in maximum to minimum dimension)[Accordance D4791]
Aggregate impact value, %	Not specified
Los Angles abrasion value, %	Max 30
Water absorption, %	Not specified
Soundness, magnesium sulphate solution, %	Not specified
Fine agg. Uncompacted void, %	Min 40 [ASTM C1252]
Fine agg. Sand equivalent value, %	Min 45 [ASTM D2491]

Although every OGFC trial have its own gradation depending on project specification. Some of the trial gradation is specified in table 2.

Table 2
Trial gradation

Sieve Size(mm)	% Passing			
	[26]	[2]	[13]	[6]
38	100	100	100	-
19	100	100	95	100
12.5	85-100	85-100	-	80-100
9.5	35-60	55-75	-	35-60
6.3	-	-	-	1-20
4.75	10-25	10-25	35	1-10
2.36	5-10	5-10	15	1-10
1.18	-	-	10	-
.075	2-4	2-4	2	1-4

The underlying stone recharge bed consist of a uniformly graded ,clean washed stone mix like AASTHO NO. 2 and AASTHO NO. 57 [11][13]. Ordinary Portland cement can be used as filler [4].Mineral filler contents specified for European PA mixtures are in the range of 3–7%, while this range corresponds to 0–4% for PFC mixtures [1].

2.2 Binder

The asphalt grade selection is based on environment, traffic, and expected functional performance of the OGFC.The preferred specified paving grade should meet Specification
ASTM D 946 [32].The use of modified asphalt cements is permitted provided that the selected asphalt grade has a PG temperature range exceeding 95 [26]. PMBs are typically used in the production of OGFC mixtures because of their rut-resistant properties [2].

2.3 Additive

The combination of a uniformly graded aggregate and low filler content can lead to the draining of asphalt binder from the mixture by gravity during storage, hauling, and placement procedures [2].Either a cellulose fiber or a mineral fiber may be used to minimize drain down. Generally a dosage rate of 0.3 % is added with respect to mixture mass [26].

Fibers stiffen a binder through absorption and by increasing surface area and the resulting fiber network. LDPE material in shredded form in of approximately 2 × 2 mm in size has been used as additive [2].

3. Effects of a Permeable Friction Course on Highway Runoff

Porous asphalt have a considerable impact on the quality and quantity of highway storm water runoff. Rain that falls on the friction course drains through the porous layer to the original impervious road surface at which the water drains along the boundary between the pavement types until the runoff emerges at the edge of the pavement.PFC might be expected to reduce the generation of pollutants, retain a portion of generated pollutants within the porous matrix, and impede the transport of pollutants to the edge of the pavement [9].

In addition to safety benefits, PFC has also been shown to reduce concentrations of pollutants commonly observed in highway runoff.The porous asphalt had a 60% reduction in solids load compared to conventional pavement. Load reductions for total copper (Cu) and total lead (Pb) were 31% and 56%, respectively. A 55% increase in the loading of total zinc (Zn) was found for the pervious surface [6].

A study in the Netherlands compared runoff water quality from porous overlays and conventional pavement surfaces .Lower concentrations of pollutants were observed in runoff sampled from the porous asphalt than from impervious asphalt for many of the constituents monitored. Specifically, total suspended solids (TSS) concentrations were 91% lower, total Kjeldahl nitrogen (TKN) 84% lower, chemical oxygen demand (COD) 88% lower, and total copper (Cu), lead (Pb), and zinc (Zn) ranged from 67 to 92% lower than in runoff from the conventional asphalt pavement[6]. The dissolved fractions of copper and zinc were higher in the runoff from porous asphalt overlay [9].

The study done by (cahill 2003) result that show elevated levels of chloride, and electroconductivity in the winter months. Minor amounts of PAHs (low ppb range) in the water samples were attributed to the very rapid infiltration of stormwater through the crushed rock and lack of fine silt or organic layer that would enhance pollutant attenuation through microbial activity [11].

However, water velocities within the pore spaces of the PFC are low and likely could only transport the smallest material .Several studies have been conducted to examine the distribution of solids and associated pollutants on road surfaces. These studies generally indicate that the majority of pollutants are located about 1 m of the curb [9]. These data indicate that the PFC has little to no effect upon the concentrations of dissolved constituents in the storm-water runoff [9].

4. Belowground Effect Of Porous Pavement

Impermeable pavements cover a considerable land area in cities. Their effect on the hydrological cycle is clear as a barrier in the soil–atmosphere continuum they minimise rainfall infiltration and evaporation.Soil physical and chemical conditions like moisture content, temperature and pH are critical for plant growth.

pH affect the mineral solubility in both organic and mineral soil. The soil was more alkaline beneath porous, rather than impervious pavement. The reasons for this are that porous pavements contain a greater proportion of cement than impervious pavements and their hydraulic conductivity is relatively high. Soil moisture was recharged beneath PP but remained at low level beneath impervious pavement [5].

5. Characterization Of PFC Mixes

5.1 Assessment of mixture volumetric properties

The high total AV content of PFC mixtures and the consequent difficulty to obtain representative results associated with saturated surface dry measurements of porous specimens led to the use of either the vacuum method [4] or dimensional analysis [1] as the two most common alternative methods to compute G_{mb}. The G_{mb} of each compacted mix was determined using the geometric measurements of diameter, height, and the mass of the specimen in air, in accordance with ASTM D 7064[26][4].

The bulk specific gravity ,G_{mm} is measured using the Standard Test Method for Theoretical Specific Gravity and Density of Bituminous Paving Mixtures, ASTM D2041-03a [32].Also known as Rice Specific Gravity. This method uses uncompacted mixture specimens produced at the target asphalt binder content selected in the design range. Recent research recommended a computation procedure for G_{mm} of PFC mixtures, which resulted in higher accuracy and reliability as compared to the conventional Rice Specific Gravity. The recommended method included measuring G_{mm} at two low asphalt binder contents (3.5% and 4.5% were suggested) to determine the average effective specific gravity of the aggregate (Gse), and then calculating G_{mm} at the target asphalt binder content chosen in the design range (6–10%) [1].

Based on a comparison of the vacuum method and dimensional analysis, NCAT recommended the vacuum method [3].Computation of the water-accessible AV content (i.e., proportion of the total volume of a compacted PFC mixture that is accessible to water) was initially explored in 2003 by Watson using the vacuum method. In 2009, Alvarez .recommended dimensional analysis (over the vacuum method) to compute this AV content. The water-accessible AV content directly related to mixture functionality and durability [1].

6. Assessment of mixture durability

6.1 Cantabro Loss Test

The Cantabro test is the laboratory test most commonly used to evaluate durability for mix design and evaluation, and to conduct research on both PFC and PA mixtures. In the Cantabro test, a compacted specimen is placed in the Los Angeles abrasion machine (without abrasive load) and subjected to 300 revolutions. The Cantabro loss, expressed in percentage, corresponds to the ratio of lost weight to initial weight of the compacted specimen. The test should be conducted at a standard temperature at 25°C [1][4][20][23][17].

The cantabro resistance test is used to determine abrasion resistance of PFC,PCPC and PA [20][23].The maximum Cantabro loss specified, for specimens tested in dry- and wet-conditions, subsequently defined, is 20% and 35%, respectively [23].

The recommended maximum permitted abrasion loss in aged condition is 25% [2] and for unaged condition is 20% [2][3][23]. The aging process is performed by placing the specimens in a forced draft oven at 60°C for 7 days before testing. Samples were placed in the oven to stimulate the field effects of oxidation on the asphalt binder. The temperature was set at 60°C [2].

6.2 Draindown Test

According to Watson , PFC mixtures typically exhibited an asphalt binder film thickness of approximately 30µm,while the corresponding thickness for dense-graded HMA is typically about 8µm. This difference and the small fine aggregate content in PFC mixtures (as compared to that of dense-graded HMA) lead to higher susceptibility for the asphalt binder to drain off the aggregate skeleton in PFC mixtures [1][26].

Based on research conducted on stone matrix asphalt, NCAT proposed a test for draindown assessment, which is also applicable for evaluation of PFC mixtures[1]. The mix design procedure proposed by NCAT [3] and ASTM D6390-11 [27] included this draindown test. The draindown is usually limited to 0.2% or 0.3% [1][4].

6.3 Stone To Stone Contact Test

Quantitative determination of the existence of stone-on-stone contact in the coarse-aggregate fraction of the compacted PFC mixture is required to ensure the design of a mixture with adequate resistance to both permanent deformation and disintegration.

In 2002, NCAT [3] proposed a method to assess the existence of stone-on-stone contact in PFC mixtures based on the comparison of AV in the coarse aggregate (VCA) (i) the compacted PFC mixture (VCAmix) and (ii) the corresponding dry-rodded compacted aggregate (VCADRC). According to this method, stone-on-stone contact is achieved when the VCA ratio (i.e., VCAmix/VCADRC) is equal to or smaller than 1.0, since the coarse-aggregate fraction of the compacted mixture achieves a stone-on-stone contact condition similar to that obtained by the dry-rodded compacted aggregate.[1][29][4][23][26].

6.4 Moisture Susceptibility

The moisture susceptibility of the PFC mixes was evaluated based on the tensile strength ratio (TSR). The TSR refer to the ratio of average indirect tensile strength (ITS) of the wet-conditioned subset to the average indirect tensile strength of dry-conditioned subset, tested at a temperature of 25 ± 1°C. Six identical specimen for each mix were prepared, out of which, each set comprising three specimens were used for ITS tests at dry- and wet-condition according to the ASTM D 6931-12 [25][4][2]. The wet-conditioning was carried out as per the AASHTO T 283 [33][4]. The retained tensile strength (TSR) should be at least 80 % [26][2].

The indirect tensile strength of laboratory fabricated or field recovered specimen is determine according to ASTM D6931-12 [25]. The mixtures with PE fibers showed improved TSR values, resulting in improved resistance to moisture-induced damage when compared with mixtures without fibers [2].

6.5 Boiling Test

This practice is useful as an indicator of the relative susceptibility of bituminous-coated aggregate to water, but should not be used as a measure of field performance because such correlation has not been established [1][31].

Visually observe the aggregate (coarse and fine) for retained bitumen coating .Any thin, brownish, translucent areas are to be considered fully coated. Visual observations shall be made immediately after the sample is placed on the white paper towel [31].

6.6 Permeability Test

Drainability is one of the most important characteristics of PFC mixtures, since it is closely related to several of the advantages exhibited by these mixtures under wet weather. However, most agencies do not specify direct measurement of the coefficient of permeability thus most common approaches for mix design include (i) targeting a minimum total AV content value as an indirect index of adequate permeability and (ii) optional measurement of permeability on laboratory compacted specimens [1][4][16]. For these optional measurements, a minimum permeability value of 100 m/day was suggested by NCAT [3] and ASTM International (D 7064-04) [26].

However, as proposed in recent research, selection of minimum values of permeability should be conducted based on the rainfall events expected at the project location [1].Constant head laboratory testing has shown that PFC experiences a nonlinear flow relationship,described by the Forchheimer equation.

$$I = aq + bq2$$

In addition to the laboratory analysis of the hydraulic characteristics, a falling head field test is recommended to determine the in situ hydraulic conductivity[14].The field permeability can also measured by using NCAT and ASTM C1701 [21][28].

6.7 Freeze And Thaw Test

The freeze–thaw test was conducted to determine the freeze thaw resistance of pervious concrete mixtures using procedure of ASTM C666 [35], in which specimens were subjected to continuous freezing and thawing in the saturated condition. Relative dynamic modulus (RDM) and mass loss were used to characterize the freeze–thaw durability of pervious concrete.

7. Conclusion

The findings obtained from an extensive literature review focused on the basic aspects related to mix design and evaluation of PFC mixtures and identifies corresponding areas of study for future improvement. After implementation of PFC mixtures in the 1990's, significant evaluation were obtained. However, mix design procedures still needs primarily on evaluation of volumetric properties to select the optimum asphalt binder content. Several techniques and approaches summarized in this literature review can be integrated in a modified mix design procedure with increased reliability for determination of the optimum asphalt binder content and prediction of mixture properties and performance.

Future research, however, is required to be able to fully integrate aspects related to functionality, like noise reduction effectiveness and drainability and durability in the mix design procedure and replace indirect assessments. PFC mix design now a day is evaluated from the application of tools such as X-ray CT and image analysis techniques to optimize the mixture internal structure and, consequently, optimize both durability and functionality. These analyses should also be conducted to optimize the aggregate gradation to maximize functionality in terms of content, size, and distribution of AV as well as durabilty in terms of stone-on-stone contact of the coarse-aggregate fraction.

8. Future Enhancement

1. We can use hydrated lime & poly fiber and report the result by using Marshall Compaction.
2. For some gradation of sample what the difference between using Asphalt Rubber-PFC & performance grade-PFC.
3. It is recommended that AR-PFC binder content 5.5-7%; PG-PFC (8-10%), but we are using <6% then what is the performance difference using different % of bitumen.
4. Aggregate compaction method's and their effect largely affect the durability of PFC.
5. We can carry drain down test to measure the what effect made by oil and fuel dripping on durability of PFC.
6. Drain down test on aged specimen and it's result study for repeated no. of test.
7. Conducting drain down & abrasion test., before and after doing of short term and long term aging.
8. How can we measure the roughness of PFC marshall sample/specimen and effect of roughness with aging?
9. We can prepare marshall specimen using PFC gradation & testing them for flow, AV, VMA…all six criteria whatever we are using in dense DBM to provide optimum blinder content.

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