



Performance Assessment of Porous Friction Course (PFC) Mix modified with Cement as Filler Material

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Abstract: Porous Friction Course (PFC) mix are the type of open-graded bituminous mixtures used as wearing courses over the dense bituminous mix surfaces of pavement. These are mainly provided to serve as surface drainage layers to improve pavement surface permeability, skid-resistance, and visibility and also to mitigate hydroplaning effect during wet-weather conditions, in addition to reduction of vehicle tyre noise. In this present work mix designs were performed according to the Marshall Design procedure for a range of 4.5–5.5% binder content. This research has investigated the effect of aggregate gradation and binder content on the volumetric and performance related properties, including air-void, void in coarse aggregate for both dry rodded and mix condition, stone on stone contact, draindown, unaged abrasion loss, aged abrasion loss and permeability of PFC mix with neat bitumen (VG 30). The optimum mix obtained in this study is having a medium gradation with 5.0% binder content

Keywords: Porous Friction Course; Open-Graded Bituminous Mixtures; Marshall Design; Aggregate Gradation; Optimum Mix.

I. 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. [1]. Porous friction courses or Open-graded friction courses (OGFC) can also be explained as the mixes, which can be used to improve surface frictional resistance, provide additional storm water management measures, minimize hydroplaning, safety measures for drivers and pedestrians due to reduced splash and spray during rain, improve night visibility, lower pavement noise levels [2,3] and also reduced potential for black ice or ice due to improper drainage [4]. Apart from various benefits, the different terminologies which are used for PFC mixes throughout the world, includes open-graded asphalt (OGA), open-graded friction courses (OGFC), porous asphalt (PA), and porous friction course (PFC). In the United States permeable friction course (PFC) mixtures are termed new generation open-graded friction course (N-OGFC) mixtures, and similar European mixtures are identified as Porous Asphalt (PA) [5]. Basically, in dense-graded pavements, the surface course is designed to be impermeable so the water must move to the edge of the road by way of a small cross slope or camber, which is constructed in the pavement. However, in a porous asphalt pavement, the entire structure is designed to allow water to infiltrate the surface and then be stored in the base prior to exfiltration into the subgrade. Fig. 1 shows the movement of water within (a) a porous asphalt pavement, (b) an asphalt pavement with a porous friction course (PFC) or open-graded friction course (OGFC) overlay, and (c) a conventional dense-graded asphalt pavement [6].

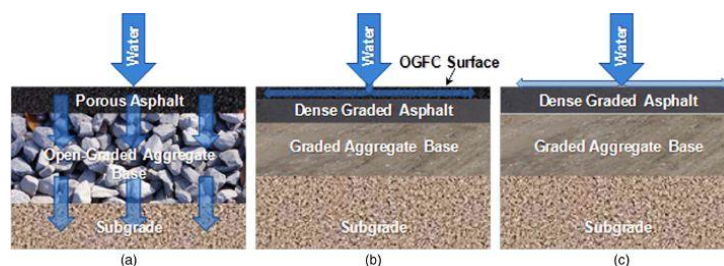


Figure 1 Water movement through (a) porous asphalt pavement; (b) asphalt pavement with an PFC or OGFC overlay; (c) conventional asphalt pavement [6]

II. Background

In the late 1960's, the Franklin Institute Research Laboratories (United States) have commenced a research into a new type of pavement structure and finally with the support of the United States Environmental Protection Agency (EPA), a porous pavement program was developed. This new pavement structure was initially installed in parking lots [7]. A porous pavement incorporating PFC layer permits water to pass freely through the pavement structure by reducing or controlling the amount of run-off from the surrounding area either from precipitation or elsewhere from the surrounding environment. By allowing precipitation and run-off to flow through the structure, this pavement type can be applied as a storm water management practice. This particular types of pavements may also result in a reduction in the amount of pollutants entering the ground water by filtering the runoff [8]. The original proposed structure of a porous pavement consisted of an open-graded surface course placed over a filter course and an open-graded base course (or reservoir) all constructed on a permeable subgrade [7]. They are generally designed for parking areas or roads with lighter traffic. Yet, there exist some dis-advantages of this pavement type. In general there is an absence of practical expertise in these types of pavements mainly in cold climates. Although, National Asphalt Pavement Association (NAPA) had identified two major types of porous pavements: porous asphalt and pervious concrete. Each type of porous pavement is a variation of the respective conventional impermeable pavement design, whereas, porous asphalt consists of an inter-connected void system containing open-graded coarse aggregates bonded with asphalt cement and fibres, whereas the pervious concrete pavement consists of Portland cement, uniformly open-grade coarse aggregates, and water combined using special porous mix designs [4].

Research findings on PFC mixes are rarely reported from India [9-12], but the findings reported by them shows an extensive research on various aspects of PFC mixes. Literature shows that a high percent air voids content and enhanced permeability will significantly improve the performance of PFCs. Therefore, rapid oxidation of the asphalt binder films [13] and moisture susceptibility have an adverse effect on the structural stability of such types of pavement surfaces. Apart from that, one of the major findings based on a review of TRL road trials on porous asphalt showed that porous asphalt surfaces have a service life of more than 10 years on heavily trafficked roads, although binder hardening was considered to be a major limiting factor [14]. Even, experiences with use of open-graded mixes in the United States showed that raveling was the main cause of pavement failure in some sections, while majority of states had an enhanced experience with the use of polymer modified asphalt binders [15]. Likewise, Suresh *et al.* [16] summarizes the details of the laboratory investigation by using three different aggregate gradations with three different modified binders and neat bitumen on the performance and durability of porous friction course (PFC) mixes. But, James *et al.* [17] reported that porous pavements can easily get compacted and clogged with sediments. As a result, the pavements have to be reconstructed once every 8 years and it has also been reported that porous pavements can easily be rutted by traffic and freeze easier than normal pavements. In brief, the research findings based on laboratory investigations mentioned above, recommend the use of modified binders to improve the durability of PFC mixes. However, in India mostly neat bitumen are used in the road construction purposes, therefore, it is significant to understand how the PFC mix can perform using neat bitumen with using cement as a filler material.

III. Objectives of the Present Study

The primary objective of this study was to evaluate the mix design and performance properties of PFC mixes corresponding to the gradation suggested by ASTM D7064 [18]. To accomplish this objective, the mix design properties considered are volumetric properties (Stone on stone contact condition, Bulk density, Air void etc.), permeability, unaged abrasion loss, and drain down. Further, the performance properties considered is aged abrasion loss.

IV. Materials Characterization

The Porous Friction Course (PFC) mixes corresponding to aggregate gradation shown in Table 1 were investigated. Coarse and fine aggregates obtained from Pachami stone quarry near Mohammad Bazar at Birbhum district in the state of West Bengal were used in this study. Portland Pozzolana Cement (PPC) was used as the mineral filler, where the quantity of PPC was limited to 3% by mass of the total aggregates. The physical properties of coarse aggregates, and paving-grade bitumen were determined in accordance with Indian Standard (IS) test methods. The grade of bitumen used is of VG 30 grade obtained from Indian Oil Corporation Ltd. through Emas Expressway Pvt. Ltd, India. The test results are presented in Table 2 and verification of aggregate and bitumen specification is done according to MORTH-2013 [19] and IS: 73-2006 [20]. Specific gravity value of PPC cement in absence is assumed as 3.00 for PPC [21].

Table 1 Mid-Range Aggregate Gradation recommended by ASTM D7064 [18]

IS Sieve Size, mm	19	12.5	9.5	4.75	2.36	0.075
% Passing	100	92.5	47.5	17.5	7.5	3

Table 2 Properties of Aggregates and Bitumen

Materials	Properties/Test	Test Method	Test Specification	Test Results
Aggregates	Grain Size Analysis (%)	IS 2386 Part I	Max. 5% passing 0.075mm sieve	1.14
	Flakiness & Elongation Index (%)	IS 2386 Part I	Max. 35% (Combined)	24.67
	Aggregate Impact Value (%)	IS 2386 Part IV	Max. 24%	12.28
	Los Angeles Abrasion Value (%)	IS 2386 Part IV	Max. 30%	19.34
	Water Absorption (%)	IS 2386 Part III	Max. 2%	0.55
	Stripping (%)	IS 6241	Min. Coating 95%	>95
Bitumen (VG 30)	Penetration Test at 25°C.	IS 1203	50-70	57
	Softening Point, (R&B), °C	IS 1205	Min. 47	50.5
	Ductility at 27°C, cm	IS 1208	Min. 40	>100
	Flash Point, °C	IS 1209	Min. 220	320
	Specific Gravity	IS 1202	Min. 0.98	1.02

V. Experimental Design

PFC mix corresponding to the gradation and three Binder Contents (BC) of neat bitumen were investigated. Cylindrical specimens of 100 mm in diameter and 63.5 mm in height for the selected PFC mix were prepared by the Marshall Impact Compactor with 50 number of blows on both sides. In total, 27 cylindrical PFC specimens that constituted minimum of three replicate specimens for the experimental mix were prepared to evaluate the volumetric properties, coefficient of permeability (K), Cantabro abrasion loss (Unaged (UAL), Aged (AAL) and 9 un-compacted mix were used to evaluate the drain down characteristics.

VI. Evaluation of PFC Mix

A. Volumetric Properties

The volumetric properties of compacted specimens tested included the bulk specific gravity (Gmb), percent air voids (Va), and the Voids in Coarse Aggregate (VCA). The Gmb was determined using the mass of the specimen in air, water and in saturated surface dry condition. The theoretical maximum density (Gmm) of the un-compacted mix was determined in accordance with ASTM D 2041 [22] by evaluating effective specific gravity of aggregates (Gse), where the effective specific gravity of the aggregate is constant because the asphalt absorption does not vary with variations in asphalt content. Va was then determined using the corresponding values of Gmb and Gmm using Eq.(1). Presence of stone-on-stone contact condition in the compacted PFC mix was evaluated based on the percent voids in coarse aggregate of the compacted mixture (VCA_{mix}) and the percentage of voids in coarse aggregate in the dry rodded condition (VCA_{drc}) determined using the dry-rodded test procedure. The VCA_{drc} and VCA_{mix} values were computed using Eq.(2) and (3), respectively. Stone-on-stone contact condition in the mix was confirmed when the ratio of VCA_{mix} to VCA_{drc} was found to be lesser than unity.

$$Va = [(Gmm - Gmb) \times 100] / Gmm \quad [1]$$

$$VCA_{drc} = Gca \gamma_w - \gamma_s / Gca \gamma_w \quad [2]$$

$$VCA_{mix} = 100 - [(Gmb / Gca) \times Pca] \quad [3]$$

Where, Gca = bulk specific gravity of the coarse aggregate; γ_s = bulk density of the coarse aggregate fraction in the dry-rodded condition; γ_w = density of water; PCA = percentage of coarse aggregate in the total mixture.

For tests conducted on PFC mix, the mean values of test results corresponding to the Gmm, Gmb, ratio of VCA_{mix} to VCA_{drc} , and Va are presented in Table 3. The mean value of VCA_{drc} is 47.71%. The mean maximum specific gravity (Gmm) of the aggregate gradation ranged between 2.60 g/cc and 2.56 g/cc. The mean bulk specific gravity of compacted mixes (Gmb) ranged between 2.013 g/cc and 2.039 g/cc. The mean values of Va for the mix varied from 20.35% and 22.57%; and the results indicates that 4.5% binder content have the highest amount of air void while mix with 5.5% having lowest, but all the mixes were found of having higher air void then limiting value (% AV > 18). The mean voids in coarse aggregate mix VCA_{mix} ranged between 36.87% and 44.59%. The ratios between VCA_{mix} and VCA_{drc} presented in Table 3, confirm the presence of stone on-stone contact condition in the coarse aggregate skeleton in all the experimented mix combinations tested as the results ranged from 0.74 to 0.89. Thus, the mix ensures adequate stability to resist the plastic deformation as well as resistance to permanent deformation and disintegration.

Table 3 Volumetric Properties

BC (%)	Gmm	Gmb	Va	VCA_{mix}	VCA_{drc}	VCA_{mix} / VCA_{drc}
4.5	2.60	2.013	22.57	36.87	49.71	0.74
5.0	2.58	2.033	21.20	40.94		0.82
5.5	2.56	2.039	20.35	44.59		0.89

B. Permeability

The performance of PFC mix is directly related to its drainage characteristics. The drainage characteristic of these mixes are evaluated by measuring permeability. For determining the permeability of Marshall Specimen the circumferential contact area between the specimen and the mould was covered on either side to prevent the leakage of water. In this method water was poured through a saturated asphalt mixture, and the interval of time in seconds (t) was recorded for water to fall from some fixed initial head (h_1) to a final head (h_2) [23]. The typical setup for permeability test using falling-head method is shown in Fig. 2. The co-efficient of permeability (K) was calculated using Eq.(4) and results varied in the range from 93 to 159 m/day. Thus, the mix at 5.0 and 5.5% binder content satisfied the permeability criteria that K should be more than 100 m/day for good drainage condition. Table 4 indicates the mean K values of the mixes tested and Figure 3 shows the comparative analysis of permeability with air void. However, it is generally accepted that the permeability is directly proportional to the porosity (percent air voids, V_a) and the results showed the similar variations in the permeability to that of trends of air voids.

$$K(\text{m/day}) = \frac{(3600 \times 24)}{1000} \frac{a}{A} \ln \frac{h_1}{h_2} \quad [4]$$

Where; l = height or thickness of specimen in mm, a is the cross-sectional area of the standpipe in mm^2 , A is the cross-sectional area of the specimen in mm^2 , K =Permeability constant.

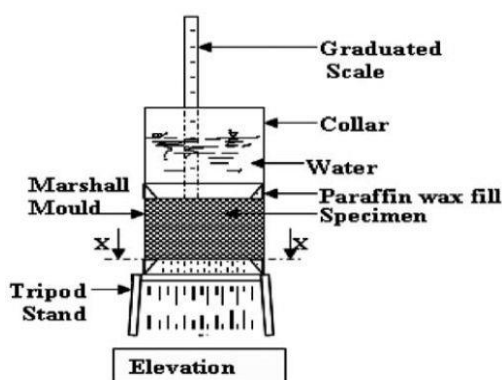


Figure 2 Permeability Test Setup

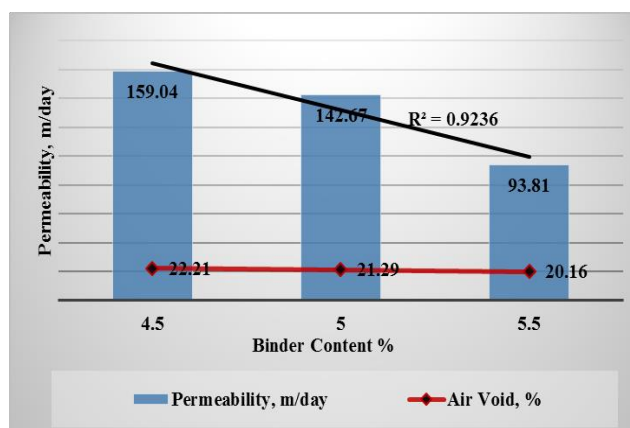


Figure 3 Comparative Analysis of Permeability with Air Void

Table 4 Permeability Test Values (K)

Binder Content (%)	4.5	5.0	5.5
Mean Value of K (m/day)	159.04	142.67	93.81

C. Cantabro Abrasion Loss

The Cantabro abrasion loss test method is used for ensuring adequate durability of the compacted PFC specimen. This test was conducted on unaged specimens and aged specimens and the corresponding abrasion losses are termed as Unaged Abrasion Loss (UAL), Aged Abrasion Loss (AAL) respectively.

The Unaged Abrasion Loss (UAL) was conducted by placing the test specimen in a Los Angeles abrasion drum (Fig.4) without any abrasive charges, and the machine was operated at a speed of 30–33 revolutions per minute for 300 revolutions. The percentage of mass loss during this process was used to evaluate the resistance of asphalt mixtures to raveling and the percentage of weight loss in the specimen when compared to its initial weight was expressed as the abrasion loss (AL).

However, because of very high air void contents the asphalt binder in PFC is prone to hardening at a faster rate than dense-graded HMA, which may result in reduction of cohesive and adhesive strength leading to raveling. Therefore, the mix design should be subjected to an accelerated aging test and aging is accomplished by placing compacted specimens (compacted with 50 blows) in a forced draft oven (Fig.5) set at 85°C for 120 hours (5 days). The specimens are then cooled to 25 °C and stored for 4 hours prior to Cantabro abrasion test. The abrasion loss on unaged and aged specimens should not exceed 20% and 30 % respectively [18] on average while the loss for any individual specimen should not exceed 50%. Sometimes, an increase in abrasion loss was expected in the aged samples when compared to the unaged samples, because aging of asphalt binders due to oxidation increases the stiffness, which causes the bond between aggregate particles and the asphalt binder to be more susceptible to breaking.

The variation of air void with UAL and AAL of mix is shown in Figure 6 and 7 respectively and the corresponding values of UAL and AAL with different binder content is shown below in Table 5.

Table 5 Unaged and Aged Abrasion Loss Test Values

Binder Content (%)	4.5	5.0	5.5
Mean Value UAL (%)	21.20	19.48	19.14
Mean Value AAL (%)	18.84	17.21	17.08



Figure 4 Unaged PFC specimen subjected to Abrasion Test

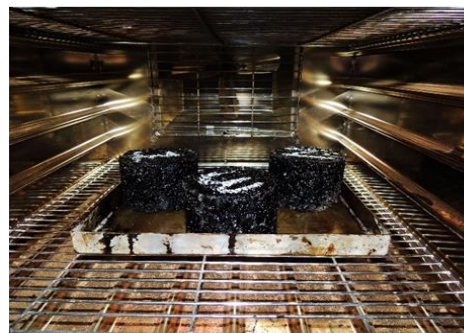


Figure 5 Aged PFC specimen subjected to Aging Process

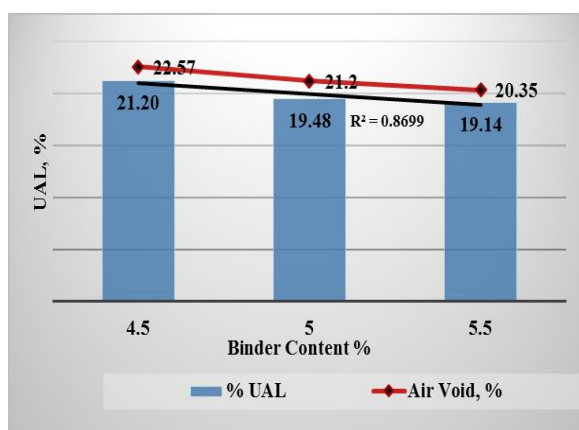


Figure 6 Comparative Analysis of UAL with Air Void

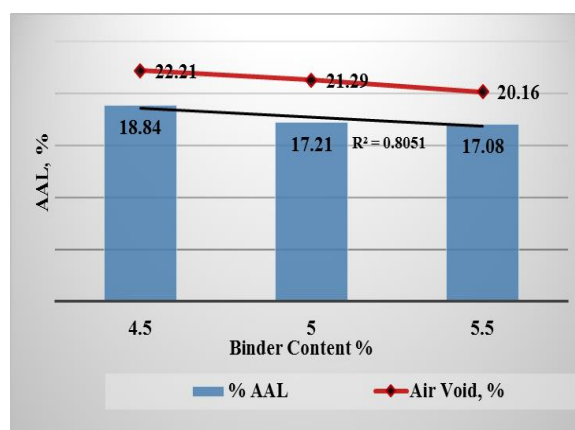


Figure 7 Comparative Analysis of AAL with Air Void

D. Drain Down

The test provides an evaluation of the drain down potential of an asphalt mixture during mixture design and field production. Basically, increase in the binder content in PFC mixes will have a tendency to cause drain down of bitumen binder during mixing, storage and/or transportation. In this study this test was carried out by using glass jars of around 98mm diameter and 136mm height. The loose mix sample is poured into glass jars and put in forced draft oven (Fig.8) at 15°C above the mixing and compaction temperature for one hour. After one hour the jar is inverted and amount of material retained on the wall of jar (Fig.9) is calculated. The test is done accordance EN 12697-18:2004 [24]. The drain down value calculated using Eq.(5) and the drain down value should be within 0.3%. The drain down values with different binder content is shown below in Table 6.

$$\text{Drain down (\%)} = \left[\frac{(\text{Final wt. of flask with drained sample} - \text{Initial wt. of flask}) \times 100}{\text{Initial wt. of flask}} \right] \quad [5]$$

Table 6 Drain down Test Values

Binder Content (%)	4.5	5.0	5.5
Mean Value of Drain down (%)	0.21	0.25	0.34

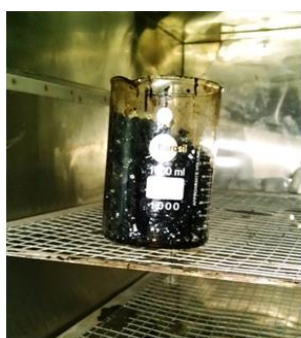


Figure 8 Loose mix in glass jar



Figure 9 Weighing of retained material on the jar

VII. Conclusion

The following conclusions were drawn from the present study:

- (i) The PFC mixes has exhibited good volumetric properties and permeability. Air voids content were found to be more than 20% and coefficient of permeability more than 100 m/day for the mixes at a binder content of 5.0 and 5.5%.
- (ii) The mix of this gradation satisfied the stone on-stone contact condition. This can be related to the presence of more quantity (> 20%) of aggregates passing 4.75 mm sieve.
- (iii) In the mixes with binder content of 5.0% and 5.5%, the mean values of UAL and AAL were found to be within the acceptable limits of 20% and 30% respectively, while the mix with 4.5% satisfies the AAL criteria only.
- (iv) The PFC mixes at a binder content of 4.5 and 5.0% are within the acceptable limit of 0.3%.

Based on these findings it can be concluded that this type of gradation can be designed with 5.0% bitumen content of VG 30 grade and it is evident that when designing porous friction course mix, it is important to understand the conditions in which the pavement will be expected to perform. However, PFC still have many unknown issues that need to be addressed and great potential to be further improved.

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