POROUS ASPHALT PAVEMENT A TENTATIVE MIX DESIGN GUIDELINES – BY NEW GENERATION OPEN GRADED FRICTION COURSE APPROACH

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ABSTRACT: **Porous asphalt pavements are an alternative technology that differs from traditional asphalt pavement designs in that the structure permits fluids to pass freely through it, reducing or controlling the amount of run-off from the surrounding area. By allowing precipitation and run-off to flow through the structure, this pavement type functions as an additional storm water management technique accounting for ground water recharge. The overall benefits of porous asphalt pavements may include both environmental and safety benefits including improved storm water management, improved skid resistance, reduction of spray to drivers and pedestrians, as well as a potential for noise reduction.**

The objectives of study were to obtain a porous asphalt mix design procedure for the achieved gradation recommended by National Centre for Asphalt Technology (NCAT) using the locally available aggregates, to determine the optimum binder content by adopting New Generation Open-Graded Friction Course (OGFC) design concept, to evaluate the performance of the mix in the laboratory in terms of Permeability, Moisture Susceptibility and Marshall Stability, and thereby develop tentative mix design guidelines for Porous Asphalt which has adequate permeability and durability that suits Indian climatic conditions

Key words: Porous Asphalt Pavements, Permeability, Drain down potential, Ageing Potential, Cantabro Abrasion, Water Sensitivity, Marshall Stability.

I INTRODUCTION

In recent years researchers, designers and builders are always looking for new and improved ways to protect the environment in the most effective ways possible. One such emerging technology is the 'Permeable pavements' that allow water to infiltrate through surfaces that would normally be impermeable, such as the dense graded flexible pavements or the rigid concrete pavements. Permeable pavements are of various types which include porous asphalt, pervious concrete, inter-locking concrete block pavers, turf reinforcing grids, decks, open graded aggregates and soft paving materials such as wood mulch.

Porous asphalt pavements offer developers and planners a new tool in their toolbox for managing storm water. These pavements allow water to drain through the pavement surface into a stone recharge bed and infiltrate into the soils below the pavement. Such pavements have been proving their worth since the mid-1970s, and recent changes in storm water regulations have prompted many consulting engineers and public works officials to seek information about them. With the proper design and installation, porous asphalt can provide cost-effective, attractive pavements with a life span of more than twenty years and at the same time provide storm-water management systems that promote infiltration, improve water quality, and many times eliminate the need for detention basin. The performance of porous asphalt pavements is similar to that of other asphalt pavements. And, like other asphalt pavements, they can be designed for many situations.

Common applications of Porous Asphalt Pavements are parking lots, side-walks, pathways, shoulders, drains, noise barriers, friction course for highway pavements, permeable sub base under the conventional flexible or rigid pavements and low volume roads. In addition, porous asphalt can also be used as an application for tennis courts, patios, slope stabilization, swimming pool decks, green house floors, zoo areas etc.,

The Economic Benefits includes:- reduction in storm water runoff, including reduction of temperature, total water volume, and flow rate, increase in groundwater infiltration and recharge, provides local flood control, improves the quality of local surface waterways, reduces soil erosion, reduces the need for traditional storm water infrastructure, which may reduce the overall project cost, increases traction when wet, reduces splash-up in trafficked areas, extends the life of paved area in cold climates due to less cracking and buckling from the freeze-thaw cycle, reduces the need for salt and sand use during the winter, due to little or no black ice, requires less snow-ploughing, reduces groundwater pollution, creates green space (grass groundcover, shade from tree canopies, etc.), offers evaporative cooling.

Porous asphalt pavements are generally not used solely for pavements for high traffic and heavy wheel loads.

II OBJECTIVE OF THE STUDY

The main objectives of the study are – to evaluate several laboratory porous asphalt specimens for Drain-down, Ageing, Cantabro Abrasion; and hence evaluate for optimum binder content, to evaluate the performance of porous asphalt specimens in terms of Marshall Stability, Permeability and Moisture Susceptibility. Finally based on the experimental results, propose tentative mix design guidelines for 'Porous Asphalt Pavement'.

III METHODOLOGY

The methodology adopted for study includes – selection of granite aggregates from the locality, test for its suitability and obtain a desired gradation as per NCAT gradation criteria for OGFC [1]. Marshall Specimens with 50 blows of compaction are subjected to air void confirmation, drain down, ageing and Cantabro abrasion tests for varying binder contents and hence optimum binder content is obtained. Compacted specimens prepared using optimum binder content and are checked for Marshall Stability, Permeability and Moisture Susceptibility tests to evaluate the performance of Porous Asphalt.

IV MATERIALS SELECTION

A. Selection of Aggregates

The aggregates used in the porous asphalt mix consisted of crushed angular granite stone with maximum size not exceeding 19 mm. Granite stone was chosen as coarse aggregate as it is a common higher quality aggregate available in the vicinity of Bangalore.

Table 1 Physical Characteristics of Road Aggregates - Test Results

Sl. No.	Desirable Property of Aggregates	Name of the Experiment	Result	Permissible Value Specified by IRC (for bituminous surface course)
1	Specific Gravity	Specific Gravity	2.66	2.5 to 3.2
2	Toughness	Aggregate Impact Value	14.15%	< 30%
3	Strength	Aggregate Crushing Value	18.32%	< 30%
4	Shape of Aggregates	Flakiness Index	12.30%	< 15% and should not exceed 25%
5		Elongation Index	7.22%	< 15 %
6		Angularity number	6.68	0 to 11
7	Hardness	Abrasion loss	32.96%	< 40 %
8	Water Absorption	Water Absorption	0.30%	should not exceed 1%

B. Selection of Binder

Porous asphalt consists of a high percentage of interconnected air voids (>15%). Because of a high amount of air voids in porous asphalt, aging resistance of the binder becomes crucial. Void content in asphalt mix determines the rate of aging by controlling oxygen access to the binder. Higher air voids would facilitate the oxidative aging of the binder even deeper in asphalt pavement. Aging makes bituminous materials harder and more brittle, thus increasing risk of pavement failure, such as ravelling and cracking [2].

Crumb Rubber Modified Bitumen has been shown to have the ability to improve the rutting resistance, resilience modulus, and fatigue cracking resistance of asphaltic mixes. This is due to the alteration of the property of the bituminous binder in terms of the viscosity, softening point, loss modulus, and storage modulus. The improvement is governed by the swelling process of rubber particles that interact with bitumen. Rubber crumbs can swell up to 3 to 5 times its original size due to the absorption of molten component of the bitumen. This left a higher proportion of asphalt in the binder, therefore increasing its viscosity.

In the present dissertation work, Crumb Rubber Modified Bitumen (CRMB-60) was used throughout the study for the preparation of the porous asphalt mix.

V ACHIEVING THE DESIRED GRADATION

The different sized aggregates were mixed together for obtaining the desired gradation defined by National Centre for Asphalt Technology (NCAT) [1] by adopting the method of 'Proportioning of Materials by Rothfutch's Method' and thus the proportions of various aggregate sizes were obtained.

Table 2 Sieve Analysis Results of Aggregates after Proportioning

Sieve Size	% Passing of Aggregate Fraction (As obtained by Rothfutch method)					Percentage Passing for OGFC Mix as per NCAT
	20 mm	12.5 mm	6 mm	Quarry dust	Combined	
	15.04%	71.3%	10.63%	3.03%	100%	
19	15.04	71.30	10.63	3.03	100.00	100
12.5	3.01	69.80	10.63	3.03	86.47	85-100
9.5	0.31	57.33	10.63	3.03	71.29	55-75
4.75	0.01	6.02	5.07	3.01	14.12	10-25
2.36	0.01	2.67	1.64	2.42	6.74	5-10
0.075	0.00	0.89	0.02	0.27	1.18	2-4

VI OPTIMUM BINDER CONTENT

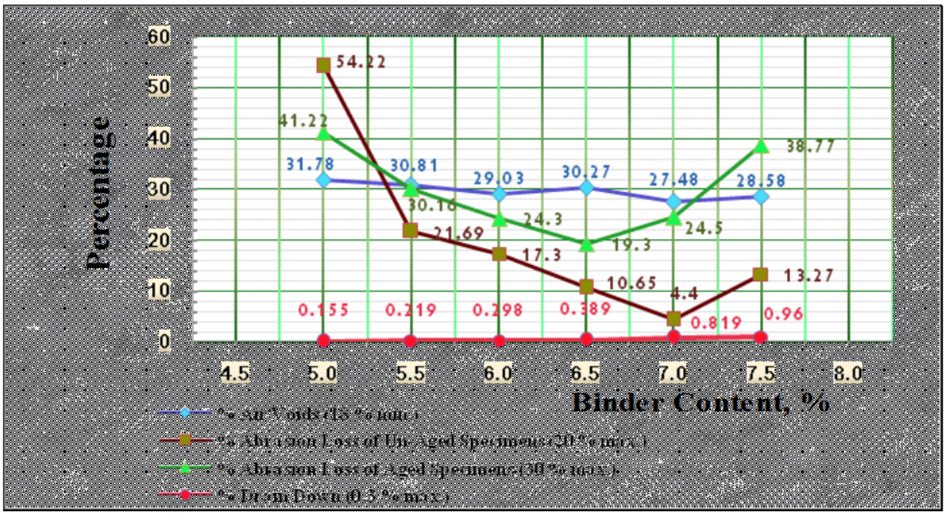
The National Asphalt Pavement Association [NAPA] recommends that the optimum asphalt content for porous asphalt be determined by asphalt content that meets the following requirements: air voids greater than 18 % and drain down less than 0.3 % [3]. However the National Centre for Asphalt Technology recommends the optimum asphalt content for OGFC as air voids greater than 18 %, drain down less than 0.3% and in addition to these two, it introduces two more requirements to be met, namely: Cantabro Abrasion of un-aged specimens less than 20 % and Cantabro Abrasion of aged specimens less than 30 % [1].

In the present dissertation work the criteria recommended by NCAT for obtaining optimum binder content for OGFC was adopted. The test results of various experiments conducted on Porous Asphalt Specimens for determining optimum binder content, namely: - Air Void content, Cantabro Abrasion, Ageing Potential and Drain Down Potential are tabulated below.

Table 3 Determination of Optimum Binder Content for Porous Asphalt Mix

Sl. No.	Binder Content %	Air Voids %	Cantabro Abrasion Loss (Un-Aged) %	Cantabro Abrasion Loss (Aged) %	Draindown Potential %
		18% min.	20% max.	30% max.	0.3% max.
1	5.0	31.78	54.22	41.22	0.155
2	5.5	30.81	21.69	30.16	0.219
3	6.0	29.03	17.30	24.30	0.298
4	6.5	30.27	10.65	19.30	0.389
5	7.0	27.48	4.40	24.50	0.819
6	7.5	28.58	13.27	38.77	0.960

Determination of Optimum Binder Content for Porous Asphalt Mix



From the above graph and observations it is clear that the binder content of 6 % fulfils all the criteria recommended by NCAT for OGFCs. Therefore the **bitumen content of 6 % is finalized as the optimum binder content** for Porous Asphalt throughout the dissertation work and is adopted for performance evaluation of Porous Asphalt.

VII PERFORMANCE TESTS

The following are the performance tests results carried out on the Porous Asphalt specimens. Three performance tests were conducted which included Permeability, Moisture Susceptibility and Marshall Stability.

Table 4 Permeability of Porous Asphalt Specimen

Bitumen Content, %	5.5	6.0	6.5
Co-efficient of Permeability cm/s	0.49	0.39	0.33

Table 5 Tensile Strength Ratio of Porous Asphalt Mix

No. of Blows	50	60	75
Tensile Strength Ratio, TSR, %	69.93	77.61	81.14

Table 6 Marshall Stability and Flow of Porous Asphalt Mix

No. of Blows	Marshall Stability, kg	Flow, mm
50	1213.6	4.60
60	1395.3	3.75
75	1607.2	2.36

Permeability is one of the critical properties, as it marks the ability of the porous asphalt to properly drain the fluid through the system. The falling head permeability test was conducted using a permeability test set up in the laboratory. The Permeability test was conducted on nine cylindrical porous asphalt specimens, (150 mm dia., and 150 mm ht.) by varying the binder content in increments of 0.5% for three binder content values, namely – 5.5%, 6.0% and 6.5%.

One of the initial concerns regarding the durability of Porous Pavement is its resistance to freeze-thaw damage. So it is necessary to check the resistance of compacted Porous Asphalt mixtures to moisture-induced damage and to investigate the effects of saturation and accelerated water conditioning under freezing and thawing cycles. But as in the locality (Bengaluru, Karnataka) the freezing temperatures are most rarely to prevail therefore not much importance was given to conditioning under freezing. Hence the test for Moisture Susceptibility was carried out by conditioning the Porous Asphalt Mix specimens in water bath maintained at 60° C for 24 hours, followed by placing the same specimens in a water bath maintained at 25° C for 2 hours and then subjecting these specimens to Indirect Tensile Test.

Marshall Stability test was conducted on compacted cylindrical specimens of porous asphalt mix of diameter 101.6 mm and thickness 63.5 mm. The specimens were prepared by adopting the same procedure as that followed for the specimens of Marshall Mix Design. The Porous Asphalt Mix specimens were kept in water bath maintained at ***25^0 C for a period of one hour before testing as against 60^0 C*** which is followed by Marshall Stability test.

VIII CONCLUDING REMARKS

Based on the observations made on various tests results, the following concluding remarks may be derived:-

i. The aggregate gradation consists of 100 percent of 19 mm down sized aggregates but requires less than 15 % of the aggregate fraction passing 4.75 mm, so that the compacted mix becomes permeable and provide adequate permeability.
ii. In order that the stone-on-stone contact condition is achieved in Porous Asphalt pavements, it demands the use of modified binders such as Polymer modified Bitumen or Crumb Rubber modified Bitumen.
iii. For the Porous Asphalt to be permeable, air voids content of 18 percent and above is necessary.
iv. The abrasion loss of the un-aged Porous Asphalt can be reduced significantly by increasing the percentage binder content or by using a modified binder such as the Crumb Rubber modified Bitumen due to improved flexibility.
v. The tests on the drain down potential of Porous Asphalt specimens reveals that binder contents exceeding 6 percent shows more drain down loss of binder exceeding the permissible value of 0.3 percent [1].
vi. Permeability test results at various binder contents reveal that an increase in binder content decreases the value of co-efficient of permeability
vii. The Moisture Susceptibility test conducted on Porous Asphalt specimens at different levels of compaction effort reveals that increase in compaction effort shows improvement in the values of Tensile Strength ratio.
viii. Increase in compaction effort has also revealed the rise in the values of Stability of the Porous Asphalt specimens and fall in the flow values.

IX MIX DESIGN GUIDELINES

Based on the experimental results and conclusions of this study, the following tentative Mix Design approach is proposed the design guidelines for 'Porous Asphalt Pavement'.

A Selection of Aggregates and Binder

The first step in the mix design procedure for 'Porous Asphalt Pavement' is the selection of the materials that are suitable for its design. It mainly includes the selection of aggregates and binder.

The aggregates used for the surface course of the 'Porous Asphalt Pavement' should be crushed angular stone with maximum size not exceeding 19 mm with the aggregates passing 4.75 mm IS sieve not more than 10 percent and shall meet the requirements of Indian Standard Specifications, IS : 2386 (Part I, II, III, IV) – 1963.

Porous Asphalt Pavements demands the use of modified bitumen which may be either Polymer modified of Crumb Rubber modified. The selection of the binder shall be made in accordance with IRC: SP: 53 (First Revision), 2002 and shall confirm the specification requirements as under 'Polymer and Rubber Modified Bitumen – Specifications, IS: 15462 – 2004'.

B Design Gradation

The Design Gradation shall fall within the gradation range for Porous Asphalt Pavement as defined by National Centre for Asphalt Technology (NCAT) [1] for OGFCs. If required, the different sizes of aggregates proportioned and combined by adopting Rothfutch approach.

Sieve Size, mm	**Percentage Passing %**
19	100
12.5	85 – 100
9.5	55 – 75
4.75	10 – 25
2.36	5 – 10
0.075	2 – 4

C Determination of Optimum Binder Content

Porous Asphalt Mix Specimens compacted with 50 blows of Marshall Rammer are prepared by adopting the desired gradation mentioned above using binder content in increments of 0.5 percent. The specimens are subjected to the following tests so as to fulfil the criteria given by NCAT:

i. **Air Voids.** A minimum of 18 percent is acceptable, although higher values are desirable.
ii. **Abrasion Loss on Un-aged Specimens.** The abrasion loss from the Cantabro test should not exceed 20 percent.
iii. **Abrasion Loss on Aged Specimens.** The abrasion loss from the Cantabro test should not exceed 30 percent.
iv. **Drain down.** The maximum permissible drain down loss should not exceed 0.3 percent by total mixture mass.

The binder content which fulfils all the four requirements is selected as optimum binder content. If none of the binder contents meet all four criteria then a remedial action becomes necessary which may include the use of stabilizers and modifiers into the mix.

D Performance Evaluation

i. **Permeability**: Cylindrical Porous Asphalt specimens are subjected for falling head permeability test. The co-efficient of permeability of 100 m/day is acceptable.
ii. **Moisture Susceptibility**: Porous Asphalt Mix specimens are conditioned in water bath maintained at 60°C for 24 hours, followed by placing the same specimens in a water bath maintained at 25° C for 2 hours and then subjecting these specimens to Indirect Tensile Test; the results of which are compared with the unconditioned specimens. TSR value more than 80 percent is considered acceptable.

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ANNEXURE

Fig. 1 Compacted un-aged Specimens subjected to Cantabro Abrasion test

i. Before Test ii. After Test

Fig. 2 Compacted aged specimens subjected to test for Ageing Potential

i. Before Test ii. After Test

Fig. 3 Un-Compacted specimen subjected to test for Drain-down Potential

<<< Fig. 4 Pictorial view of compacted specimens for Permeability test (150x150) mm^2

Fig. 5 Falling Head Permeability Test >>>

<<< Fig. 6 Pictorial view of compacted specimens used for Moisture Susceptibility test

Fig. 7 Pictorial view of Indirect Tensile test on Porous Asphalt Specimen >>>