Using of Open-Graded Bituminous Mixtures in Iraq

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Abstract
Open graded mixtures or porous asphalt mixture (PAM) is mainly implemented on surface drainage layer on the pavements of the high-speed trafficked highways because it has many application advantages such as : noise reduction and safety throughout the rainfalls, as a result of its open structure, the water is stored and horizontally moved inside the layer, reducing the effects of the splash and spray, thereby increasing the drivers' visibility throughout the rainfalls. Alternatively, the main drawback of the porous asphalt layers are the low stiffness, high rutting and durability. The aim of the present research has been comparing the impact of 2 types of modifier (which are, the propylene modifier [PP] and the styrene-butadiene-styrene [SBS]) on efficiency of the porous asphalt mixture. The evaluation of PAM has been based upon the asphalt flow drains down, air voids, and abrasion resistance at the step of the mix design. The performance of the mix has been investigated by permeability, rutting and moisture susceptibility. The test results have emphasized the significance of the use of the modifier in the minimization of abrasion loss, reduction of the rutting and enhancement of the PAC mix durability. The porous asphalt mixes that were prepared with 5% SBS modifier have been the most effective at increase of abrasion resistance and reduction of the rutting; and PP did not have any effects on the strength of the mixture.

Keywords: Open graded mixtures, Draindown, Polyproline, porous asphalt and styrene butadiene styrene

1. Introduction

Porous asphalt **(PA)**, which has been referred to as the open-graded **(OG)** asphalt as well, was used since 1950's as wearing surface. Its first main utilization in Australia has started in approximately 1973 and in Japan has started about 1987. The porous asphalt is a developing in the technology of the road surfacing; the porous asphalt is a new technology of road surfacing, allowing the water to enter in asphalt mixtures beyond the continuous air voids. The PA has been designed so that after the laying and compacting, they create a surface with a void's over 20%. They have been utilized in the wearing courses and always laid on the water-resistant base course, has been promising and effective in the enhancement of the traffic safety. Utilization of the porous asphalt as well for the reduction of the glare and noise [1] with the suitable installation and maintenance, the PA allows infiltrating about 80% of the runoff volume per year.

Porous asphalt has been utilized all over the world due to its favorable spray and splash characteristics, as well as its reduction of the Aquaplaning under the rain conditions in addition to its characteristics of the noise reduction. Switzerland began to use the porous asphalt in 1979 with mixed results. Based on a review that has been conducted in 2004, 9 out of 26 cantons utilize the porous asphalt. Particularly, the canton Vaud in western Switzerland has been known a leader in the promotion and utilization of the porous asphalt. Presently, about one third of Vaud motor-ways are covered by the PA and its utilization has been planned to extend to the majority of motor-way surfaces in canton Vaud up to a 600 m altitude. Moreover, there is a number of the bridge trial sections with the porous asphalt. In spite of its advantages, the PA can be suffering from some issues that may have an impact on its service life as well as performance. Open structure exposes a wide surface area to water and air effects, which results in the rapid binder aging. Also, pore clogging may result in the premature reduction of the functionality [2].

PA application is providing skid resistance, in particular in wet seasons, and that is considerably better compared to that of the dense graded asphalts. The possibility of the aquaplaning, considerably decreased at normal speeds of driving, and in combination with the enhanced visibility, can be one of the significant benefits for the use of this mixture type. PA is a mix type, which is made up of relative coarse aggregates that are bound together by a mix of the filler, sand and bitumen which is referred to as the mortar thereafter. After the laying and the compaction this yields a structure that has a rather

large amount of the interconnected voids. In comparison to the dense asphalt concretes, PA concrete has quite an open structure with the contents of the void about 20% [3]**.** The enhancements mainly included using modified asphalt binders and fibers, which have resulted in the alleviation of some issues that have been encountered with the open-graded friction courses in U.S. [4], [5] & [6].
The objective of the present paper is to measure some lab characteristics of PAM for the purpose of evaluating the design of porous asphalt mixture and the performance of modified and unmodified PAM. The mix design process including the determination of the aggregated gradation, drain down properties, air void analysis, Cantabro Abrasion Test (aging and un-aging tests), and optimum asphalt content to achieve these properties of porous asphalt mixture without modifier and modified with SBS.

2. LITERATURE REVIEW

The porous pavement systems have the ability of providing a very good system for removing the pollutants, 2 long term monitoring pavements in Virginia and Maryland have provided an estimation of the capability of the PA for removing the pollutants. The efficiency and storage capacity of a system depend upon the clogging degree in the porous system. With the suitable maintenance, the porous system must have the ability for the effective removal of the pollutants [7].
The content and the type of the binder are of a very high importance, as these influences selecting the suitable grading that will significantly affect the mixture's structural integrity. The binder has to be as well in sufficient amount for providing for the durability and abrasion resistance, 3 asphalt cement binder properties have been taken under consideration as highly important for the pavement performance in the service. Those are: viscoelasticity, temperature susceptibility and aging [8].
AASHTO T305, Determining the Drain down properties in the Uncompacted Asphalt Mixes, is presently the most commonly accepted approach of testing method in U.S. for the determination of the drain down (i.e. the survey results). Similarly, to approaches that have been discussed previously, the differences in the mass prior to and post the oven storage have been utilized for the determination of the drain down. None-the-less, in this approach, none-the-less, the mixture has been held in woven wire basket, which allows the drain off of the binder through the wire. Figure2 depicts this testing in progress. A different test which is usually deployed, in particular, with the open-graded mixes, is Cantabro test, where, the compacted specimens of the mix have been tumbled in a LA abrasion test drum, with no steel balls utilized in Los Angeles abrasion test. The changes in the mass prior to and post the testing indicates the mix's durability. The fibers were stated to result in enhancing this durability in a number of the cases [9], [5] have confirmed the appropriateness of Superpave gyratory compactor for the preparation of the specimens for the Cantabro test rather than Marshall compacted specimens that have been utilized originally.
Austroads drain down testing approach is similar to German approach in that 1kg of the mixture is put in tared glass beaker, after that, held for 60min ± 1min prior to turning the beaker upside down, which allows the fallout of the mix. In Austroads approach, the temperatures of the oven have been specified based on the type of the mixture (i.e. SMA or open-graded) and whether a modified binder has been utilized or not; the specified temperature degrees are in the range between 160ºC for the unmodified OGFC and 185ºC for the modified. Moreover, a supplementary process may be utilized with the polymer-modified binders in the case where the remaining binder amount in the beaker is > 0.30% of original mixture mass. This process includes the use of a solvent for washing residue from a beaker via a tarred 0.600mm sieve for the determination of whether or not a considerable amount of fine aggregate particles has been trapped in modified binder that adheres to a beaker [10].

3. METHODOLOGY

The method that has been adopted for the present research includes selecting the asphalt paving materials from the locality , test for its suitability and obtain a desired gradation as per NCAT gradation criteria for porous asphalt mixtures (Marshall Specimens with 50 blows of compaction are subjected to air void confirmation, drain down, ageing and Cantabro abrasion tests for various binder contents and hence optimum binder content is obtained. Compacted specimens prepared utilizing the optimum binder content and are checked for Marshall Stability, Permeability, Moisture Susceptibility and rutting tests for the evaluation of the Porous Asphalt performance.

4. Materials used

In the present study, the materials that have been used in preparing asphalt mixtures were divided into aggregate with two different gradation, two types of asphalt cement as it will be indicted below.

4.1 Aggregates

The aggregate that has been utilized in the present study is the crushed quartz that has been obtained from AlNibaie quarry; this aggregate has been commonly utilized in the local asphalt paving. The aggregates that have been utilized in PA mixes included the (crushed) coarse aggregate and a screenings fine aggregate. A small filler amount has been utilized as well in this specific design of the mixture. The routine tests that have been carried out upon the aggregate for the evaluation of their physical characteristics. **Table 1**. Test results have shown that the selected aggregate meets the specifications of the Superpave.

Table 1. Characteristics of used aggregate type

characteristic	**ASTM -15**	**Results of Tests**	**Standard Specification limitations**
Coarse Aggregate ;			
1.Bulk Specific Gravity (Gs.)	C - 127, **[15]**	2.64	…
2.Apparent Specific Gravity (Gs)	C - 127,**[15]**	2.66	…
3. Absorption of Water, (%)	C- 127,**[15]**	0.34	…
4. 5. Angularity	D- 5821**[16]**	97 %	Min 95%
5. Los Angeles Abrasion, (%)	C-131,**[17]**	18	35 Max
6. Soundness	C-88,**[18]**	3.0 %	10-20% Max
7. Elongation and Flat particles of aggregate	D-4791,**[19]**	2.4 % , 0.8 %	Max 10%
Fine Aggregate ;			
1.Bulk Specific Gravity, (Gs.)	C-128,**[20]**	2.651	…
2.Apparent Specific Gravity, (Gs.)	C-128,**[20]**	2.67	…
3. Absorption of Water, (%)	C-128,**[20]**	0.42	…
4. Equivalent sand	D-2419 ,**[21]**	85.6%	Min 45%

The filler may be defined as a non- plastic material that passing sieve No200 (0.075 mm). In the present study, the asphalt mixtures have been prepared with the use of the Portland cement as mineral filler. The Portland cement was obtained from Local market of Baghdad governorate. The physical characteristics of fillers have been listed in Table .2 below.

Table2. Characteristics of the Portland cement filler

Physical characteristics	Specific gravity	Surface area (m^2/kg)	% Passing sieve No200(0.075mm)
Result	2.41	244	94

The chosen gradation follows the National Asphalt Pavement Association [11], for the PA paving mixes for (19mm) aggregate maximal sizes are shown in Table3.

Table3. The gradation for porous asphalt mixtures

Sieve Size mm	National Asphalt Pavement Association (NAPA, 2003)	Mid Specification
19	100	100
12.5	85-100	93
9.5	55-75	65
4.75	10-25	18
2.36	5-10	8
0.075	2-4	3

4.2 Asphalt Cement

Asphalt cement (PG 70-16) according to Alani et al 2013 was obtained from Al-Dora refinery in Baghdad city. These binders were used on the high-ways that were carrying high traffic load and hot climate. Table4 summaries the properties of asphalt type.

Table4. Asphalt cement properties and superpave specifications

Test Parameter	PG70-16	Specification (AASHTO M 320)
Average 7days max pavement design temperature, °C	70	58
Minimal pavement design temperature, ºC	-16	-16
Properties of original binders		
Cleveland open cup flash point, ºC (AASHTO T48)	238	230°C, min
Rotational Viscometer (RV) at 135ºC, Pa.s (AASHTO T 316)	1.02	3Pa.s,max
Dynamic Shear , $G^*/\sin\delta$ at 58°C at 10rad/sec, kPa (AASHTO T 315)	1.80	1kPa, min
Properties of residue binder from rolling thin film oven test (AASHTO T240)		
Mass Loss , % weight (AASHTO 240)	0.44	1%, max
Dynamic Shear , $G^*/\sin\delta$ at 58°C at 10rad/s , kPa (AASHTO T 315)	3.36	2.2 kPa, min
Properties of residue binder from pressure aging vessel (PAV) test (AASHTO R29)		
Dynamic Shear , $G^*.\sin\delta$ at 25°C at 10rad/s , kPa (AASHTO T 315)	3576	5000 kPa, max
Creep stiffnes m-value at -6 ºC (AASHTO T313) S-value , MPa	288	300 MPa ,max
m-value	0.51	0.3, min
Direct tension failure strain at -6 ºC @ 1.0 mm/min, % (AASHTO T314)	2.32	1.0 %, min.

4.3 Modifiers

SBS can be defined as a thermo-plastic polymer improving the overall efficiency of the asphalt pavement through the increase of stability, elasticity, and stiffness of asphalt binders [12]. The SBS is softened under the high degrees of the temperature; which is why, it may be added easily and mixed with asphalt binder. The SBS polymer that has been utilized the present work, has been obtained from Kraton Company in France. SBS has been added to the asphalt binder with a (1, 3, and 5%) percentage by the weight of asphalt. Table 5 presents the SBS properties. Polypropylene fiber was obtained from MIX UK Ltd company in England.

Table 5 The main properties of polypropylene and SBS

Material	Properties	Value
Polyproplene Fiber	Specific gravity	0.91g/cm^3
	Specific surface area	260 m^2/kg
	Young's modulus	5.5-7 Gpa
	Tensile strength	350 Mpa
	Melting point	165 ^{o}c
	Specific gravity	0.91g/cm^3
	Flash point	375^{o}C
SBS	Density (Kg/m^3)	1247
	Melting point	197
	Apparent	White

Fig.1 indicates the photo of SBS and PP modifier types used in preparing porous asphalt mixtures.

Figure 1 Photo of SBS and propylene fiber modifier

4.4 Asphalt mixtures

Seven porous asphalt mixture types of different combinations of one asphalt type and two modifier types are coded as shown in Table 6.

Table 6 The Code for the seven porous asphalt mixtures

Asphalt mixture code	Description
Control mix	Control mix PG58-16 penetration grade asphalt
Mix 01	PG70-16 with 1 % SBS
Mix 02	PG70-16 asphalt with 3 % SBS
Mix 03	PG70-16 asphalt with 5 % SBS

Mix 04	PG70-16 asphalt with 1 % PP
Mix 05	PG70-16 asphalt with 3 % PP
Mix 06	PG70-16 asphalt with 5 % PP

5. Experimental works

5.1. Marshall Test

Selection of mid specification of aggregate gradation after that the aggregate has been initially sieved, washed, then dried to a constant weight at 110^{o}C. Fine and coarse aggregates have been combined with the mineral filler for the purpose of meeting the gradation; the combined aggregate has been heated afterwards to a (160^{o}C) temperature prior to the mixing with the asphalt cement that is heated to (150^{o}C) temperature for producing a kinematic viscosity of (170±20) centistokes. After that, the asphalt cement is added to the aggregate that has been heated, for the purpose of achieving the needed amount, and thoroughly mixed by the hand, with the use of spatula for 2 min. to the point where all the particles of the aggregate have been coated by the asphalt cement. Based on the **(ASTM D-1559)** [13, 29]**,** this approach includes preparing a cylindrical specimen, which is 2.50 ±0.05 inches (63.50mm) in height and 4inches (102mm) in diameter. The mix's temperature right before the compaction has been (150^{o}C). The assembly of the mold is put on compaction pedestal and 50 blows on the specimen's bottom and top have been applied with predefined 4.535kg sliding weight compaction hammer, and a free fall in 18inches (457.20mm). The specimen in mold has been left for cooling at the temperature of the room for 24h, after that, it is obtained from the mold with the use of the mechanical jack.

5.2 Air voids and Cantabro Abrasion Loss Test.

Cantabro loss and air voids are 2 significant mixture characteristics for the efficiency of the OGFC where the air voids and Cantabro loss are associated with the permeability of mixtures and the raveling resistance of the paving, respectively. The Cantabro test has been performed for the evaluation of the resistance to the mix particle loss based on the **(ASTM D 7064)** [14]**.** The aim of the Cantabro Loss test is the determination of Marshall compacted specimen's abrasion resistance. Those specimens are to be tested in seven days after the completion of the compaction, for 2 conditions with and with no conditioning. The specimen of the 1st condition has been placed in a water bath at 25^{o}C for 24h and has been tested afterwards in the LA Abrasion Machine (see Fig2) for 300 rotations, whereas the specimen of the 2nd condition has been directly placed in LA Abrasion Machine The specimens that have been compacted were placed individually in LA testing machine with no steel sphere. Following the rotation of the LA drum for 300 revolutions at a (30–33) rpm speed, the loose material that has been broken off from the test specimen's surface has been discarded. The specimen masses prior and post testing have been recorded. The loss percentage by the original specimen's weight has been computed as Cantabro abrasion, the test may be carried out on the un-aged samples, the aged specimens and corresponding abrasion losses have been respectively referred to as the Un-aged Abrasion Loss (UAL) and Aged Abrasion Loss (AAL). The loss in the weight of the specimen has been represented in weight ratio percentage of the disintegrated particles to initial specimen's weight has been shown in eq. 1:

$$\%\ \mathrm{L.A\ abrasion} = \frac{(A-B)}{A} \times 100 \qquad \ldots (1)$$

Where:
A represents the initial specimen's weight prior to placing in LA Abrasion drum
B represents the specimen's final weight after 300 revolutions in LA Abrasion drum

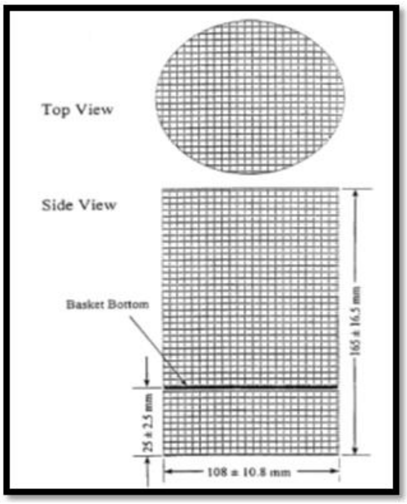
5.3 Drain Down Test

The uncompacted bituminous mix drain down properties can be assessed with the use of the test of the basket drainage **(AASHTO T305)** [15]**.** An uncompacted hot open graded mixture sample will be put in wire basket that is placed on a known weight plate. The whole setup of the test is put in oven Forced draft oven, which has the ability to maintain temperature in a range between 250º and 350º F (120º and 175º C) within ± 3.60º F (± 2º C) for 1 hr.

At the heating period end, the basket that contains the sample has been taken from the oven in addition to the plate and the plate's weight is specified. Fig2 illustrates the wire-basket sketch, the drain down amount has been considered as the material portion separating itself from the entire sample and gets deposited on a plate. The wire basket that will be utilized for this test has been made from the wire-mesh of 6.3mm (0.25inch) opening. The wire-basket's depth is 165mm ± 16.5mm, and its width is 108mm ± 10.8mm, with a basket bottom 25mm ± 2.5mm from the wire basket assembly's bottom. The binder drainage loss has been computed based on equation 2:

$$\%\text{Drainage loss} = \frac{(D-C)}{(B-A)} * 100 \qquad \ldots (2)$$

Where**:**
A represents the empty wire basket mass, (g)
B represents wire basket and sample mass, (g)
C represents empty catch plate or container mass, (g)
D represents catch plate or container plus drained material's mass (g).



A. Basket drain down B. Sketch of Wire-Basket C. Asphalt flow drain down

Figure 2 Drain down test

5.4 Permeability

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 test of the Permeability has been performed on 9 cylindrical PA specimens with 100mm height and 100mm diameter at the optimal asphalt content for every one of the PA mixtures. The process has been completed as per the process of the manufacturer. The summary of the procedure has been as follows: every one of the samples has been securely wrapped with the thin plastic wrap, and secured afterwards in the metal mold. The permeameter has been placed afterwards upon the sample's top surface in mold. After that, the moldable sealant has been applied around the permeameter's base. Four 5-pound weights have been put on base for the prevention of a break in sealant. As soon as the apparatus has been secured with the sample, permeameter has been filled by the water at the steady rate. As soon as water had reached the meter's top and has been left to settle, the rate at which level of the water had dropped has been specified. A 10cm water level change has been assessed for every one of the time trials. The time has been

recorded over a variation in head of 10cm. The variation in the height of the head (10 cm) and time (s) has been recorded for every one of the sequences. The sequence has been completed 5 times for each one of the samples and an average permeability of the coefficient has been computed.
The permeability coefficient has been calculated with the use of the following equation:

$$K = (a\,L / At)\,\ln(h1/h2) \qquad \ldots (6)$$

K = permeability coefficient
L = sample length (cm)
h1 = initial head (cm)
h2 = final head (cm)
a = inside cross-sectional area of standpipe (cm^2)
t = elapsed time between h1 and h2 (s)
A = permeameter's cross-sectional area through which that water has the ability of penetrating the area of the pavement (cm2)

The test of the permeability has been carried out at a 17 ºC water temperature, which is why a 1.08 temperature correction factor has been implemented on every permeability coefficient measurement from Florida Department of Transportation (FDOT) testing for Measuring Compacted Asphalt Paving Mixture's Water Permeability [18, 25 & 28].

5.5 Evaluation of Moisture Sensitivity

The test of the moisture susceptibility that has been utilized for the evaluation of the HMA for stripping has been done by performing AASHTO T-283[19]. This test is not a performance-based test but serves two purposes. In this test, 2 sub-sets of the test specimens are produced, those are compacted in Marshall hammer and achieving an air void content approximately seven percent [13].
As a result of the presence of water, the bond between aggregate of the mixture and asphalt binder may be lose, the stripping of asphalt pavement depends on several factors: asphalt and aggregates characteristics, environment and traffic. This accomplished by applying AASHTO T283 and ASTM D 4867. 100 mm specimen's diameter was compacted at the target air voids (20 %) with 50 gyration. Six samples were used for the designed mixture, divides to three controlled samples and three conditioned samples immersion at 60.

5.6 Wheel Tracking Permanent Deformation Testing

Pavement Wheel Tracker can be defined as a device to test the asphalt mix wearability through the simulation of the conditions of the road-way. The test gives the information on the permanent deformation rate from a moving, concentrated load. It utilizes Linear Value Displacement Transducer (LVDT) for measurement of the specimen deformation. The loaded wheel implements approximately 700N (158pounds) of the load at the contact points and repetitively passes over sample for about 10000 cycles. In the case where maximal allowed deformation has been reached before 10000 cycles, the wheel lifts the failed sample off. Specimens have been placed in the mold and placed afterwards on carriage table for the testing, which can be seen from Fig.3.

Fig.2 : Wheel track Machine

Figure 4 Wheel track and porous asphalt mixture slab**.**

Figure 3 Wheel track and porous asphalt mixture slab**.**

6. Test Results and Discussion

6.1 Optimal Asphalt Content

As soon as the gradation of the design has been specified, it has been utilized afterwards for the preparation of numerous specimens at a variety of the asphalt contents for the purpose of determining optimal content of the asphalt. There have been 5 asphalt contents assessed 4%, 4.50%, 5%, 5.50%, 6% and 6.50% asphalt cement. Those 6 have been chosen according to the optimal practice of the engineering after the consultations with the experts of the private and public sectors. Specimens have been assessed according to the Cantabro Abrasion Testing (aging and un-aging), the properties of the drain down and an analysis of the air void. Results for each have been used for the determination of optimal content of the asphalt. The NAPA, 2003, recommended that optimal content of the asphalt for the PA be specified by the content of the asphalt meeting some requirements, such as: air voids > 20% and drain down <0.30%. However the National Centre for Asphalt Technology recommends the optimum asphalt content for OGFC as air voids > 18%, drain down < 0.30% 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 % . The test results of various experiments conducted on Porous Asphalt Specimens for determining optimal binder content, which are: -Air Void content, Cantabro Abrasion, Ageing Potential and Drain Down Potential are tabulated below.

The NAPA [11] recommend that optimal asphalt content for the PA be specified by content of the asphalt, meeting the following requirements air voids > 18 % and drain down <0.30% .However the National Centre for Asphalt Technology recommends the optimum asphalt content for Open Graded Friction Coarse OGFC as air voids ranges (10-25 %), asphalt flow drain 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 % .Optimum asphalt content will be determined from figures 4 through 10 below.

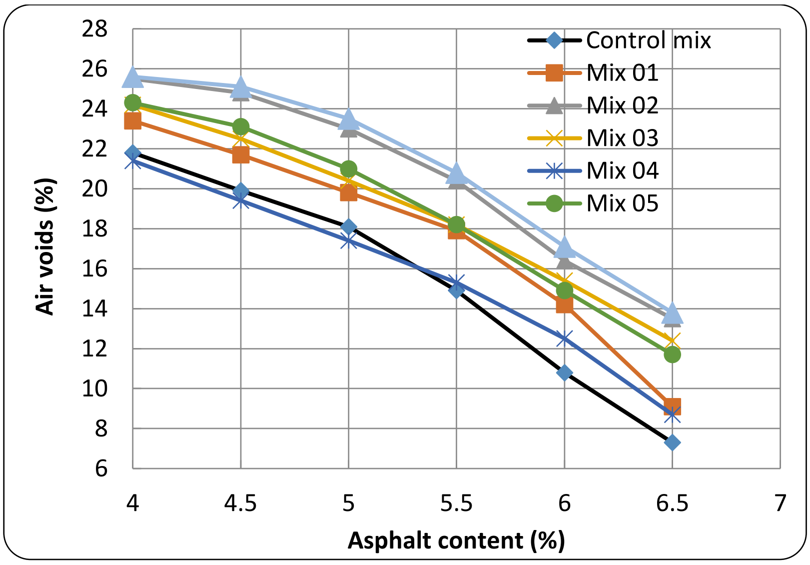


Figure 4 The Air void for various porous asphalt mixtures

The mixtures of the PA have considerably higher percentage levels of the air voids for the purpose of promoting the sufficient infiltrations. A percentage of air voids that range between 16% and 22% (or higher) was advised [11, 23 - 28].

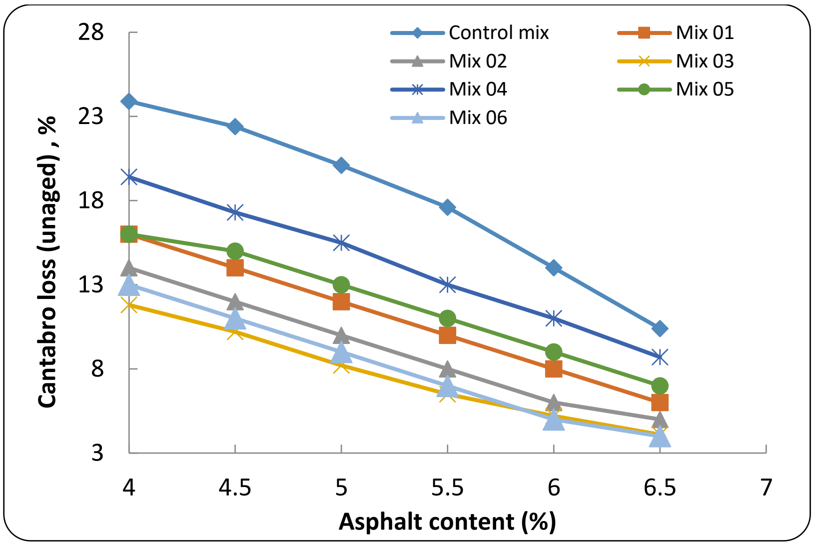


Figure 5 The abrasion loss (un-aging)

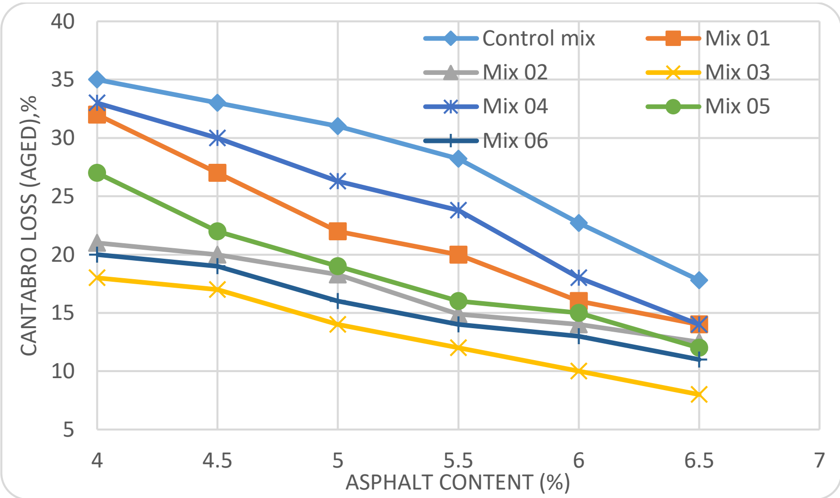


Figure 6 The abrasion loss (aging)

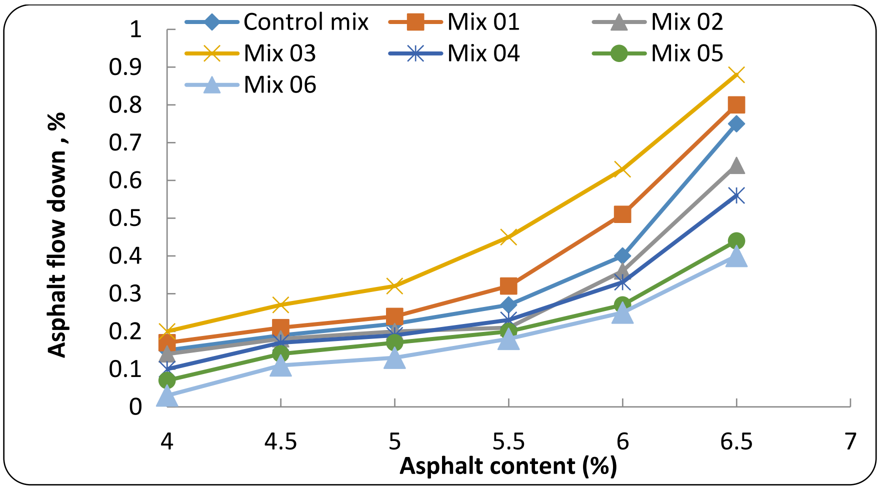


Figure 7 The drain down results

Referring to Figs.5 and 6 the abrasion losses in the Cantabro test for un-aged and aged conditions for Mix 03 with 5 % SBS polymer by weight of asphalt were lower compared with the other porous asphalt mixes. The use of modified PA mix with high percentage of SBS minimized the abrasion loss and, as a result, increased the mix durability.
The use of Mix 06 with 5 % PP fiber made it easier obtaining a higher resistance to drain down by 40 % reduction in asphalt flow down in comparison with control mix as shown in Figure 7. The asphalt content values which fulfill all the four requirements were selected for control and modified asphalt porous mixtures from Figures 4 to 7. The optimum asphalt content values are summarized in Table 7 below for various porous asphalt mixtures.

Table 7: Optimum asphalt content of various asphalt mixtures.

Mix type	Control mix	Mix1	Mix2	Mix 3	Mix4	Mix5	Mix 6
O.A.C (%)	5.38	4.63	4.75	4.5	5.0	4.88	5.13

6.2 Marshall Stability and Flow

Porous asphalt mix specimens compacted with 50 blows of Marshall Rammer are prepared by adopting the desired gradation mentioned above using optimum binder content values. Marshall stability, Marshall stiffness and flow are summarized in Table 8.

Table 8: Marshall stability, Marshall stiffness and flow of various porous mixtures

Mix type	Marshall stability (kN)	Marshall flow(mm)	Marshall stiffness (kN/mm)	National Asphalt Pavement Association (NAPA,2003) requirements	
Control mix	8.6	3.9	2.21	Marshall stability	*>5 kN*
Mix 01	9.4	3.8	2.47		
Mix 02	12.4	2.8	4.43	Marshall flow(mm)	*2-6 mm*
Mix 03	10.8	3.1	3.48		
Mix 04	8.7	3.8	2.29		*>2 kN/mm*
Mix 05	9.5	3.5	2.71	Marshall stiffness	
Mix 06	10.1	3.3	3.06		

Referring to **Table 8** the Mix 02 exhibits high Marshall stiffness among various porous asphalt mixtures.

6.3 Average Permeability Coefficient

Fig. 8 presents the average permeability coefficient values of various asphalt mixtures.

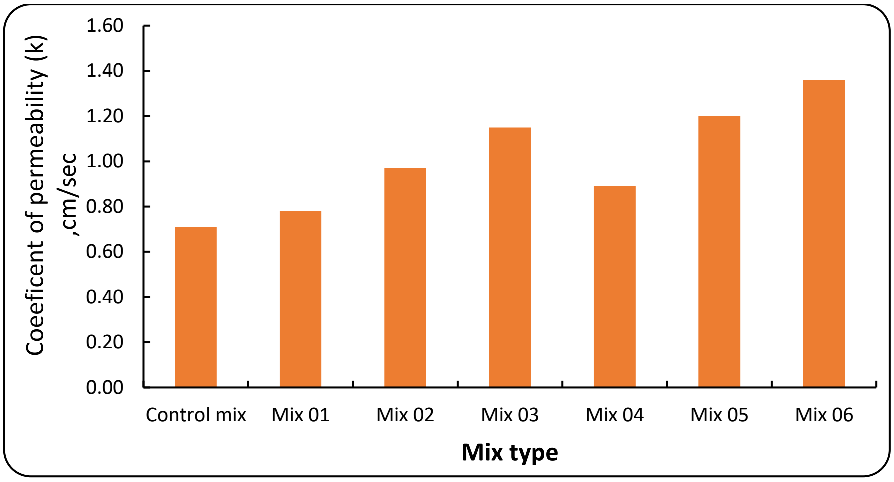


Figure 8 Average coefficient of permeability of various porous asphalt mixtures

The PA mixtures included 5 % PP give maximum permeability coefficient values amongst a variety of the PA mixes with a 90% increase compared to the control mixture.

6.4 Moisture Sensitivity

Tensile strength ratio results are clearly illustrated in Fig. 9, whereas it is apparent that as the modifier concentration increases the TSR values will increase.

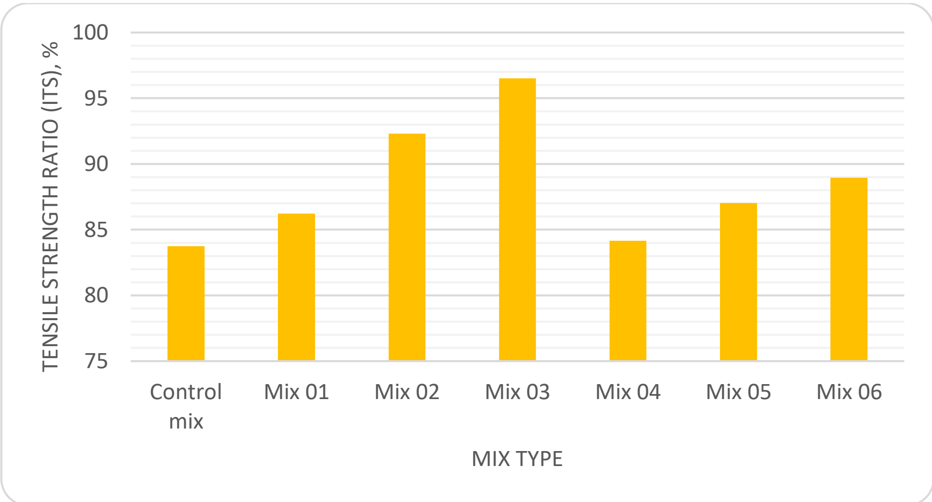


Figure 9 ITS for various porous asphalt mixtures.

As it has been illustrated in Fig. 10, adding the SBS has resulted in an increase of TSR values. The capability of SBS for the protection from the moisture damage depends upon the SBS percentages in the porous asphalt mixtures. It is recommended using 5% SBS in PA mixes due to the fact that those resistances to the moisture damages with 15 % more than control mix without any modifier. The SBS additive is effective in improving moisture resistance of hot mix asphalt [21,22, 25 &29-31].

6.5 Rut Depth

Fig. 10 presents the rut depth values of seven porous asphalt mixtures at standard temperature of 60 ^{o}C.

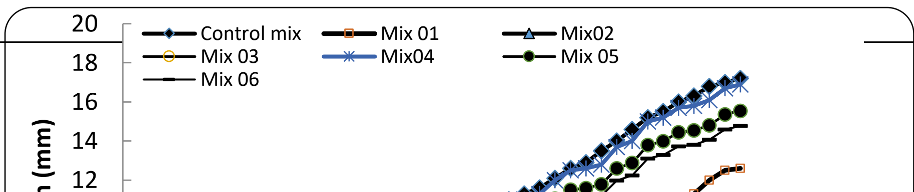


Figure 10 Rut depth values versus load cycle for various porous asphalt mixtures at 60 ^oC temperature

It can be noticed the SBS modifier has significant effect in decreasing rut depth and this effect increase with changing the SBS percentages from 1 to 5 % by weight of asphalt. The other modifier (PP) has less reduction in rut depth values. Table 9 summarizes the values of the rut depth of modified and unmodified PA mixes

Table 9 Rut depth values of various asphalt mixes

Mix type	Control mixture	Mix1	Mix 2	Mix3	Mix 4	Mix5	Mix 6
Rut depth (mm)	17.2	12.6	10.4	7.81	16.83	15.54	14.77

As it has been given in Table 9, rutting depth decreased with the increase of the SBS or PP percentages in porous asphalt mixtures. The low values of the rutting are an indication of the fact that PAC layer has good resistance to the plastic deformations, due to the fact that the PAC has coarse gradation resulting in the stone-on-stone contact. Rut depth has been in a range between 7.81mm for Mix 03 with %5 SBS and 12.6 mm for the Mix01 with 1 % SBS. The rutting depth value of Mix 04 porous asphalt mixtures modified with 1 % PP fibers was highest among modified asphalt mixtures but that value is lower than that of control mixture. Also, it can obtain from above table that the Mix 03 reduce the rut depth by 55 % as compared with control mix.

7. Conclusions

This study included laboratory evaluation of one asphalt cement (PG 70-16), two modifiers (SBS and PP) and seven PA mixes for the investigation of the performance of modified PA mixes. The following conclusions were drawn from this research:

1. A major failure that is related to the PA mixture is a result of the lack of stiffness. Asphalt modifiers may be helpful in the promotion of the adhesion between binder and aggregates and enhancing mix stiffness.
2. The abrasion losses in the Cantabro test have been lower of Mix 03 in the case of utilizing the SBS polymeric asphalt with percentage of 5 % by weight of asphalt compared with the other porous asphalt mixtures. Using SBS polymer in modified porous asphalt mixture resulted in the minimization of abrasion loss and, thus, increasing the mixture's durability.
3. Mixtures without polymers have shown greater drain down compared to the ones with the additives. The use of PP with 5 % by weight of asphalt in the mix greatly reduced the potential for asphalt flow drain down by 40 %.

4. Test results indicated that utilizing polymer-modified asphalt with 5% SBS rather than the unmodified binder reduced rutting and abrasion loss (raveling) and increased moisture damage resistance.
5. The porous asphalt mixtures with SBS polymer have the maximal strength and optimal resistance to rutting where the rut depth is reduced by 55 % in case of using Mix03 in comparison to the control mixture.

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