Study of the Properties of Open Graded Asphalt Mixtures With the addition of SBS

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Abstract. Porous asphalt (PA) is widely used in a growing number of countries where porous asphalt is applied for a variety of purposes, e.g. for the effective drainage of rainwater, traffic safety (high slip resistance), the control of noise pollution and lower temperatures surrounding the city. However, it has many other disadvantages, such as poor resistance to rutting, poor resistance to fatigue, and PA is susceptible to raveling (wastage of aggregates from the pavement surface), due to effects of climatic and traffic loading. In general, this type of mixtures is not as good as traditional mixtures. This research aims to study and improve the properties of porous mixtures using SBS. In this paper, laboratory tests were carried out to the materials involved in the composition of this mixture: binder, aggregate, and additive. SBS is used in the proportion of (2.0, 3.0, and 4.0) % of the weight of the binder. It was found that this additive leads to reduce the permeability and air void, but not as large as that without polymer modifier by (1.7 %, 3%, and 3.5%), while in the case of abrasion loss (aged and unaged) decrease by (4.1, 6.67 and 10.92) (4.7, 6.3and 2.6)% respectively. The drain down value is decreased by (16.5%, 38.25%, and 43.51%) respectively, from original asphalt cement.

Keywords: PA, Drain down, Cantabria Abrasion Loss, SBS, and Permeability.

1-Introduction
Open-Graded Asphalt, also known by different names: Graded Friction Course (OGFC), Porous Friction Course (PFC), permeable European mix (PEM) and Porous Asphalt (PA), which in Europe was mightily used, for instance, Netherlands, France, and Germany, whereas in Asia e.g. China, Japan, and Korea [1]. The open-graded asphalt mix is defined as the thin wear surface of the "HMA" hot mix asphalt, pavement that is used worldwide due to its safety properties that have an affirmative influence on a driver and is orderly used as the last lane on the interstate and high-speed low-volume expressways. Figure (1) explain the cross-section of a type of (PEM) [2].

The open-graded asphalt mix is light compared to dense asphalt mix and can cover more road surfaces. Open-graded asphalt mixture layer that improves drainage when it rains. The rainwater flows vertically through the road surface to the base course and then horizontally for the end of the road. Open asphalt mixes consist of a high proportion of coarse aggregate, which creates a high percentage of air and thus leads to rainwater flowing vertically across the road surface to the base layer and laterally to the end of the road [3]. On the other side Kandhal and Mallick, (1999) [4], studied the percentage of aggregate passing through sieve number 4.75 mm. They found that the ratio does not exceed 20% to maintain contact with a stone-on- the stone in the skeleton of the coarse aggregate and to ensure and provide sufficient permeability high air spaces in the open asphalt mixture. The benefits of open asphalt
pavement include reducing splash and spray, decrease wet skidding, diminish the risk of water planning, and improve visibility of pavement; signs in wet weather [5]. And compared to dense hot asphalt (DGHMA), this type of mixture improves driving quality and noise reduction efficiency. Also, several studies have shown that the lowest concentrations of particles and total suspended soil pollutants in the proven runoff of asphalt mixes with open gradients compared to conventional DGHMA [6]. Table (1) exhibit specifications for porous Asphalt [7].

![Image](Figure%201.%20Cross-section%20for%20OGFC%20pavement.)

| Table 1. Porous asphalt specification based on AAPA standard. |
|---------------------------------------------------------------|
| Criteria            | Marshall Standard |
| Stability           | >5 kN             |
| Flow                | (2-6) mm          |
| Air void            | (18-25) %         |
| Permeability        | >0.01 cm/sec      |
| Cantabro loss unaged| < 20 %            |
| Cantabro loss aged  | < 30 %            |
| Draindown           | < 0.3 %           |
| Indirect tensile ratio | < 0.8 %           |

2. Material
2.1. Bitumen
Bitumen cement of grade (40-50) was brought from the Central Refinery (Dora refinery) Company. The table (2) presented the general properties of the binder.

2.2. Aggregate
Aggregate utilized in this study consists of coarse material (Remaining No. 4, Sieve, 4.75 mm) and fine (Sizes of fine aggregates gradation are ranged between No.4 and No.200). This material was obtained from quarries, Al-Nibaie. Physical characteristics of the Coarse and Fine Aggregates in Tables (3) and (4) respectively.
### Table 2. Physical Properties of Asphalt Binder (Dura Refinery).

| Tests                                      | Specification (ASTM) | Value of Test | SCRBB |
|--------------------------------------------|----------------------|---------------|-------|
| Penetration (25°C-100g -5sec) (0.1mm)      | ASTM D5-13           | 43            | (40-50) |
| Ductility (25 °C, 5 cm/min)                | ASTM D113-07         | 145           | > 100 |
| Flash point (cleave land open cup)         | ASTM D92-16b         | 295           | > 232 |
| Fire points °C                             | ASTM D92-16b         | 305           | ………… |
| Softening point R&B (4±1) °C/min.          | ASTM D36-14          | 51.5          | (51-62) |
| **RV 135 °C **                             | ASTM D4402-15        | 0.432         |       |
| **RV 165 °C **                             |                       | 0.118         | ………… |
| Specific gravity at 25 °C                  | ASTM D70-08          | 1.048         | (1.01-1.05) |
| Retained penetration; % of original        | ASTM D5              | 88            | > 55  |
| Ductility of residue (25 °C - 5 cm/min)    | ASTM D113            | 130           | > 25  |

### Table 3. Physical Properties of Coarse Aggregates

| Property                        | Specification ASTM | Coarse Aggregate |
|---------------------------------|--------------------|------------------|
|                                 | sievesize(mm)     | Gsb   | Gsa   | Abs % |
| Specific gravity                | ASTM C127-128-15  | 12.5  | 2.65  | 2.67  | 0.32  |
|                                 |                    | 9.5   | 2.58  | 2.59  | 0.09  |
|                                 |                    | 4.75  | 2.57  | 2.58  | 0.18  |
| Los Angeles abrasion 30 % Max    | ASTM (C131-14)     | 21.72% |
| Fractured pieces % 95% Min      | ASTM (D5821-13)    | 98    |
| Percent flat and elongated      | Flat Elongated     | 0.9%  |
| Particles, 10 % max             |                    | 2.5%  |
Table 4. Physical Properties of Fine Aggregates

| Property                      | Specification ASTM               | Fine Aggregate | sieve size (mm) | Gsb | Gsa | Ab s% |
|-------------------------------|----------------------------------|----------------|-----------------|-----|-----|-------|
| Specific gravity              | (ASTM C127-128-15)               |                | 2.36 - 0.075    | 2.58| 2.77| 4     |
| Clay content by Sand          | equivalent% 45 min               |                |                 | 51  |     |       |

2.3. Mineral filler

Mineral filler utilized in this research is Ordinary Portland Cement collected from the local markets. Table (5) shows the physical properties of mineral filler.

Table 5. Physical Properties of Ordinary Portland Cement.

| properties                      | Results       |
|---------------------------------|---------------|
| % Passing sieve No. 200         | 97%           |
| Bulk specific gravity           | 3.20          |

2.4. Styrene Butadiene Styrene (SBS)

Modifier utilized in this research is (SBS) collected from the local markets. Table (6) shows the characteristics of the Modifier.

Table 6. Physical and Mechanical Properties for SBS polymer.

| Typical Properties               | Unit | Value   |
|----------------------------------|------|---------|
| Specific gravity                 | -----| 940     |
| Tensile strength (et)            | MPa  | 32 min  |
| Melting point                    | °C   | 180     |
| Elongation                       | %    | 88      |
| Density                          | Kg/m³| 1242    |

3. Aggregate Gradation

Depending on, ASTM-D7064 (2013) [8] the gradation aggregate shown in figure (1) and the table (7) were determined.

Table 7. Gradations of the Open-Graded Asphalt.

| Sieve Size (mm) | ASTM (D7064–13) | Trial Blend |
|-----------------|------------------|-------------|
| 3/4 inch (19.0 mm) | 100              | 100         |
| 1/2 inch (12.5 mm) | 85 - 100         | 93          |
| 3/8 inch (9.5 mm) | 35 - 60          | 48          |
4. The Experimental Works

4.1. Design of Marshall Molds

Porous friction course (PFC) specimens were prepared by mixing the aggregates, cement filler, and bitumen in its mold of Marshall (diameter 101.4mm and high 64mm) with a weight of around 1200 grams [9]. 50 blows on each side (marshal hammer) are used to compress the samples as indicated (ASTM D7064.13) [8]. Figure (2) displays some of the prepared specimens.
4.2. Mixing and Compaction Temperature
In this paper was determined temperatures (mixing and compaction) from rotational viscometer test (Asphalt Institute 2003) [10]. The results display that the temperature of mixing approximately (155 °C), and temperature of compaction approximately (144°C) as shown in Figure (3).

4.3. Open-Graded Asphalt Properties
4.3.1 volume of air voids
(Va) % was calculated for the compacted specimen according to the test method (ASTMD3203-11) [11] and (ASTMD7064-13) [8]. The percentage of air voids determined by using the following equation:

\[ Va = 100 \times \left(1 - \frac{G_{mb}}{G_{mm}}\right) \]  

(1)

where: -

G<sub>mb</sub> = Bulk specific gravity determined according to the method

9ASTMD3203-11) [11],
Gmm = Theoretical maximum specific gravity determined according to the method ASTMD2041-11) [12].

4.3.2. Cantabro Abrasion Loss
The Cantabro test is used to determine the abrasion resistance of porous pavement, this examination was conducted according to American specifications [13]. One group was tested in the unaged condition using the (Los Angeles) machine test method and the other was aged for 7 days at 140°F (60°C) in the oven. To measure the abrasion resistance of the open-graded specimens, the initial mass of a sample was measured and then the sample was placed inside the cylinder without any steel charge at speed (30-33) rpm so, that the number of rotations does not exceed ,300 rotations, at 77 °F (25 °C), after that the sample is removed and then weighed again. Figure (4) illustrate specimens before and after the abrasion loss test (Before and After Test). Allowed limits of 20 % maximum for un-aged specimens and 30 % maximum for aged specimens. Abrasion loss was calculated using Equation. Where Ai and Af are the initial and final masses of the sample, respectively.

\[
\text{Abrasion loss } \% = \left[\frac{(A_i - A_f)}{A_i}\right] \times 100
\]

(2)

![Figure 5. Abrasion Loss](image)

4.3.3 Draindown test
According to (ASTMD6390 -11) [14], un-compacted samples were prepared (the mass of the sample is 1200 ± 200 g) so that the value of draindown should not exceed 0.3 %. Then, placed the assembly in the oven at the temperature would be the anticipated plant production temperature as well as 15°C above for one hour ± 5.0 min. The assembly is removed from the oven and cooled at 24°C, as shown in figure (5). The draindown percentage is calculated using the following equation:

\[
\text{draindown } \% = \frac{(D-C)}{(B-A)} \times 100
\] 

(3)

where:
- \( A \) = mass of the empty wire basket gm,
- \( B \) = mass of the wire basket and sample gm,
- \( C \) = mass of the empty catch plate gm, and
- \( D \) = mass of the catch plate plus drained material gm.

![Figure 6. Draindown Asphalt Test.](image)

4.3.4 Hydraulic Conductivity Test (Permeability)

Permeability is one of the most important features used in the evaluation of the open-graded asphalt mixtures. The minimum value of permeability of the porous asphalt is100m/day. To determine the rate of flow water was used the Falling-Head test apparatus as shown in the figure (6). According to Darcy law, the \( K \) value is calculated for compacted paving mixture, using the following equation:

\[
K = \frac{a \times l}{A \times t} \ln \left( \frac{h_1}{h_2} \right) \times t_c
\] 

(4)

where:
- \( K \) = coefficient of water permeability, cm/s
- \( a \) = inside cross-sectional area of inlet standpipe, cm²
- \( l \) = thickness of test specimen, cm
- \( A \) = cross-sectional area of test specimen, cm²
- \( T \) = average elapsed time of water flow between timing marks, s
- \( h_1 \) = hydraulic head on specimen at time \( t_1 \), cm
- \( h_2 \) = hydraulic head on specimen at time \( t_2 \), cm
- \( \ln \) = natural logarithmic function and
- \( t_c \) = temperature correction for viscosity of water.
5. Asphalt binder content selection
Depending on test method (ASTM D 7064–13) [8], the content of asphalt for porous mixtures was determined using five ratios (4.0 to 6.0) % by weight of the mixture, with an increase of 0.5 %. Practical tests showed that the optimum asphalt ratio is (5.2) as shown in figure (7) and table (8).
Table 8. Experimental Tests Results of Marshall Specimens to Find Optimum Asphalt Content.

| AC  | Air Void | Draindown | Abrasion Un-aging | Abrasion Aging | Permeability m/day |
|-----|----------|-----------|-------------------|----------------|-------------------|
| %   | %        | %         | %                 | %              |                   |
| 4.0 | 22.8     | 0.238     | 28.8              | 47.1           | 255.15            |
| 4.5 | 22       | 0.258     | 25.64             | 41             | 250.16            |
| 5.0 | 21.1     | 0.264     | 19.5              | 28.5           | 244.78            |
| 5.2 | 20.2     | 0.285     | 18.76             | 27.7           | 242.82            |
| 5.5 | 19.3     | 0.46      | 16.78             | 26.1           | 242.61            |
| 6.0 | 18.2     | 0.63      | 15.52             | 24.3           | 238.1             |

6. The SBS polymer effect on Open-Graded Asphalt Mixtures Properties.

6.1. The SBS polymer effect on Air Voids

The results registered that the Va of the specimens containing (2, 3, 4) % modifier SBS decreased by 1.7 %, 3%, 3.5% respectively, as shown in the figure (8).
6.2. The SBS polymer effect on Abrasion Loss
From Figures (9) and (10), it is possible to notice a decrease in abrasion loss aging and un-aging for porous asphalt after adding the polymer SBS.

![Figure 10. Effect of SBS polymer on un-aged.](image)

6.3. Effect of SBS polymer on Draindown
When (2%, 3%, and 4%) SBS is added for asphalt binder the value of the draindown is decreased (16.5%, 38.25%, and 43.51%) respectively. See figure (11).

![Figure 11. The SBS polymer Effect on aged.](image)

6.4. The SBS polymer Effect on Permeability
The addition of the polymer (2%, 3%, 4%) leads to reduce the coefficient of permeability are decreased (1.42%, 2.1%, and 4.2%) respectively, from the control asphalt content value, as shown in Figure (12).

![Figure 13. The polymer effect on permeability.](image)

7. Conclusions
The following conclusions was determined based on the testing results: -
1. Comparing with un-modified mixture, air voids decreased to 1.7 %, 3%, 3.5% with SBS content (2, 3, and 4) %, respectively.
2- Draindown results show improvement after incorporating SBS polymer. For example, adding 4% of SBS polymer decreases the draindown by 43.51%.
3- Cantabro abrasion results are decreased for mixtures containing SBS polymer in comparison to traditional open-graded asphalt mixtures. For example, the cantabro abrasion loss (aging and unaging) with 4% SBS is decreased by (11.2%) and (10.9%) from control asphalt content mixture.
4- When using polymer content (2, 3, and 4) % SBS polymer the percent of permeability coefficient decreased (1.42%, 2.1%, and 4.2%).

8. Recommendations
1. It is recommended to use SBS polymer to obtain high-performance asphalt concrete and improve durability (aging and un-aging) for porous asphalt.
2. Adopting other types of polymers mixing with asphalt cement with different percentages such as Crumb Rubber (CR), High-Density Polyethylene (HDPE) and Styrene Butadiene Rubber (SBR), also using waste materials as modified such as (fly ash, slag, glasses, and plastic).

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