Enhancement of porous asphalt mixture for resisting environmental conditions using modified asphalt

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Abstract. Open-graded-friction-course (OGFC) is a hot asphalt mixture usually utilized as a private purpose wearing course, because of open graded asphalt mixture and aggregates skeleton (stone-on-stone) contact, it contains a relatively high air voids percent, after compaction which are permeable to water. In this research one sort of gradation was used (9.5 mm) NMAS for preparing the OGFC asphalt mixtures, penetration grade 40/50, crushed aggregate, asphalt content prepared with 4 % and up to 6 % by weight of mixture with 0.5 % increments. Optimum asphalt content (OAC) was selected based on these criteria: air voids content, asphalt draindown, permeability, and abrasion resistance (aged and un-aged) condition. The mix performance had been investigated by indirect tensile strength and moisture sensitivity measured according to the (AASHTO T283-14). Results illustrate that the increasing of asphalt binder content leads to decrease in the air voids content, abrasion loss and permeability values, while with draindown increase, conversely, the indirect tensile strength test (ITS) had been meaningfully increased for both conditions and this is a perfect signal of resistance against humidity susceptibility. It can be resolved that the increasing of asphalt binder % in OGFC asphalt mixture, leads to increase the thickness of asphalt binder covering around the aggregates. On the other hand the outcome indicated that the addition of 4 % styrene-butadiene-styrene (SBS) to asphalt mixture gradation equal to "9.5 mm NMAS" tends to improve the mix properties and exhibit higher TSR by (18.5, 16.4 and 13.7) % increases, as compared with original asphalt; at asphalt content (5.1, 5.6 and 6.1) %, respectively. Based on the above evaluation, the use of SBS gives the asphalt mixture better volumetric and performance properties which improved the adhesion between aggregate and asphalt that leads to reduced stripping of HMA, horizontal deformation, and increased the tensile stiffness modulus value.

Keywords: Open Graded Friction Courses, Permeability, Cantabro Abrasion Loss, Draindown, Indirect Tensile Strength and Moisture Sensitivity.

1. Introduction

Open-graded-friction-course (OGFC) is an exceptional purposely tinny wearing surface of hot mixture asphalt (HMA), also known by other names such as permeable European mix, popcorn mixture, porous mixture, and asphalt concrete friction course. Pavement that is progressively being applied
worldwide due to its driver friendly and safety aspects. OGFC is frequently applied as finishing riding surface on interstate and high speed expressways with low volume. Permeable layer of asphalt mixture improved surface drainage during rainfall, the rainwater drains perpendicularly through the OGFC asphalt mixture to an impermeable underlying layer and then laterally to the margin of the pavement. The other applications of open graded asphalt mixtures are to provide skid resistance in addition, reduces splash and spray potential, mainly in the wet season, which is obviously better than dense-graded asphalt pavement, reduced the potential of aquaplaning, and improved visibility of road markings. These mixtures contain a small percentage of fine aggregate which produces a large percent of air voids, the pavement consists primarily from coarse aggregate with a high asphalt binder content. Aggregate skeleton (stone-on-stone) is responsible for the pavement ability to resist trucks and carry the loads resulting from traffic loading without exposing pavement to cracking and permanent deformation, the load is carried by the stone while the asphalt keeps everything in place. Over 70% of the states reported an OGFC asphalt pavement service life of 8 or more years (Qureshi et al., 2015). Because of the open configuration of the layer, therefore, environmental forces such as moisture and asphalt oxidation have been a negative impact on durability (owing to the entrance of air, water, heat and ultra-violet radiation), this was improved by using modified- polymer asphalt binder (kandhal, 2004). The voids content also absorb sound energy as tires roll over the OGFC pavement, by 5 decibels (dBA) (kandhal, 2002). The higher air voids in mixture lead to reduced contact area between aggregate particles, hence leading to its lowered ITS. However, the use of modified asphalt binder significantly increases the ITS values of mixture by 18.1% as compared with asphalt mixtures without modifiers (Hamzahl et al., 2010).

2. Methodology
The methodology adopted for this study includes the selection of local materials that are widely used in the asphalt paving industry in Iraq. According to (ASTM D7064 – 13) gradation was selected; while optimum asphalt content choice was based on these criteria: air void content, drain down, cantabro abrasion and permeability for varying asphalt binder contents. Marshall specimens prepared and compacted using optimum asphalt content and were checked for moisture susceptibility to evaluate the performance of OGFC asphalt mixture.

3. Materials Properties
3.1 Aggregates
The local aggregates used in this research consist of crushed quartz, obtained from "Al-Nibaiie quarry" which is broadly utilized for asphalt mixture in Iraq. The fine and coarse aggregates utilized in this research must be washed, sieved and recombined in the proper proportions to meet the specification of wearing course gradations as required by (SCRB R/9 2003), as shown in table 1.

| Property                      | Specification | Coarse aggregate | Fine aggregate | SCRB 2003 |
|-------------------------------|---------------|------------------|----------------|-----------|
| Bulk specific gravity         | ASTM C127-128| 2.610            | 2.656          | .........  |
| Apparent specific gravity     | ASTM C127-128| 2.661            | 2.731          | .........  |
| Percent of water absorption   | ASTM C127-128| 0.55             | 0.76           | .........  |
| Los Angeles abrasion          | ASTM - C131  | 17.75            | ...........     | 30% Max   |
| Percent flat and elongated    | ASTM - D4791 | 4                | 10% max        |           |
| Fractured pieces              | ASTM - D5821 | 97               | ...........     | 90% Min   |
| Clay content by Sand          | ASTM - D2419 | ...........       | 52             | 45% Min   |

3.2 Gradation
According to "American Society for Testing and Materials" (ASTM D7064 − 13), the gradient was selected for OGFC paving mixtures. The sieve size was from 1/2 in (12.5 mm) to No. 200 (0.075mm). In this study, one sort of OGFC gradation has been used with (12.5 mm) maximum aggregate sizes (MAS). Table 2 and Figure 1 illustrates that.

| Sieve Size mm | NMAS 9.5 mm (Coarse Gradation) | ASTM D7064 − 13 | Selected % Passing |
|---------------|---------------------------------|------------------|-------------------|
| 1/2 inch (12.5 mm) | 100 | 100 |
| 3/8 inch (9.5 mm) | (85 - 100) | 93 |
| No. 4 (4.75 mm) | (20 - 40) | 23 |
| No. 8 (2.36 mm) | (5 -10) | 9 |
| No. 200 (0.075 mm) | (2 - 4) | 3 |

Table 2. Aggregate Gradation of OGFC Asphalt Mixture

![Gradations of Combined Aggregate (NMAS 9.5 mm) Used in this Work](image)

Figure 1. Gradations of Combined Aggregate (NMAS 9.5 mm) Used in this Work

### 3.3 Asphalt Binder

In this study asphalt binder with 40/50 (penetration grade) had been utilized, attained from the "Dura refinery", southwest of Baghdad. A set of ASTM tests were conducted for documentation of the physical properties of asphalt binder, as shown in Table 3. The results were in agreement with the requirement of (SCRB/R9 2003).

| Test                             | Unit         | Specification   | Value  | SCRB 2003   |
|---------------------------------|--------------|-----------------|--------|-------------|
| Penetration (25 °C-100g 5sec)(0.1mm) | 1/10 mm     | (ASTM - D5)    | 42     | (40-50)     |
| Ductility (25 °C, 5 cm/min)      | Cm           | (ASTM - D113)  | 115    | > 100       |
| Flash point                      | °C           | (ASTM - D92)   | 296    | > 232       |
| Fire point                       | °C           | (ASTM - D92)   | 329    |            |
| Softening point R&B (4±1) °C/min.| °C          | (ASTM - D36)   | 54     | (51-62)     |
| Solubility in trichloroethylene  | %            | (ASTM D2042)   | 99.4   | > 99        |
| RV 135 °C                        |              | (ASTM - D70)   | 0.56   |             |
| RV 165 °C                        | Pas.sec      | (ASTM - D4402) | 0.32   |             |
| Specific gravity at 25 °C        |              | (ASTM - D70)   | 1.04   | (1.01-1.05) |

Table 3. The Physical Properties of the Asphalt Binder (Dura Refinery)
Based on these mixing and two asphalt grade Brookfield Rotational Viscometer was used to consequent the standard Marshall hammer. Short term aging (volumetric and 6) % by blending aggregates (101.5 mm and 2.5 inches (63.5) mm in nominal height. Marshall 4. 4 and 4 and property, which company in France, the poly styrene Butadiene 3. Ductility of remainder (25 ºC - 5 cm/min) 4. Experimental Works and Laboratory Investigation 4.1 Preparation of Marshall Molds and Specimens Marshall specimen prepared according to (ASTM D6926–10), that involves a diameter of 4 inches (101.5) mm and 2.5 inches (63.5) mm in nominal height. Open graded asphalt mixtures were prepared by blending aggregates and filler (cement) with 5 different asphalt binder percentages (4, 4.5, 5, 5.5 and 6) %. The weight of sample was roughly about 1200 gm. The loose mixture were conditioned for (volumetric mixture design) in an oven for 2 hr.; at compaction temperature, while 4 hr.; at 135 ºC for short term aging (mechanical property testing) (AASHTO R30-2015). The mold assemblage employed on the compaction platform and “75 shocks” on each face (bottom and top) of sample, was done, via the standard Marshall hammer. The specimen was left to cool at ambient temperature previous to consequent testing, as shown in figure 1.

4.2 Mixing and Compaction Temperatures Brookfield Rotational Viscometer was used to determine the viscosity of asphalt 40-50 “penetration grade” that was conducted according to (ASTM D4402-15). Asphalt Institute (2007) mentions perfect asphalt binder compaction and mixing viscosities corresponding to (0.28±0.03 and 0.17±0.02) Pas.sec, respectively. Figure 3 exhibits the semi-logarithmic correlation between temperature and viscosity, and two degree of temperatures (135 and 165) ºC adopted. From the gradient line, the compaction and mixing temperatures were found to be in the range of (142 - 150) ºC and (157 - 163) ºC, respectively. Based on these outcomes, the essential compaction and mixing temperatures were 150 ºC and163 ºC.

| Retained penetration; % of original | % | (ASTM - D5) | 87.6 | > 55 |
| Ductility of remainder (25 ºC - 5 cm/min) | cm | (ASTM - D113) | 72 | > 25 |

### Table 4. The Physical Properties of Modification Asphalt

| Test | Unit | Specification | 4% SBS |
|------|------|---------------|-------|
| Penetration (25 ºC-100gm -sec) | 1/10 mm | (ASTM - D5) | 34 |
| Ductility (25 ºC, 5 cm/min) | cm | (ASTM - D113) | 142 |
| Flash point (cleave land open cup) | ºC | (ASTM - D92) | 325 |
| Softening point | ºC | (ASTM - D36) | 73 |
| Solubility in trichloroethylene | % | (ASTM D2042) | 99.4 |
| RV 135 ºC | Pas.sec | (ASTM - D4402) | 1.35 |
| RV 165 ºC | | | 0.72 |
| After Thin-Film Oven Test (ASTM - D1754) | | | |
| Retained penetration; % of original | % | (ASTM D5) | 81 |
| Ductility of remainder (25 ºC- 5 cm/min) | cm | (ASTM D113) | 105 |
4.3 Volumetric Properties

4.3.1 Theoretical Maximum Specific Gravity (G_{mm}). Maximum theoretical specific gravity is a virtual value representing a compressed sample without air voids, obtained according to (ASTM 2041-11).

4.3.2 Bulk Specific Gravity of Mix (G_{mb}). Bulk specific gravity of the competed mixture has been determined by using the geometric measurements of specimens, according to (ASTM D3203-11).

4.3.3 Air Voids (A_v \%). According to test method (ASTM D3203/D3203M–11) air voids percent was found for compacted OGFC bituminous paving mixtures, and can be defined as the total size of small air pockets between the coated particles of aggregate throughout a compacted paving mixture.

4.4 Cantabro Abrasion Loss Test
This test was carried out on Marshall sample for un-aged and aged condition according to (ASTM D7064 - 13), to obtain the abrasion damage of specimens equipped with 4 to 6 \% asphalt binder percent consuming the "Loss Angeles" container without the charge of steel spheres, machine was revolved (300) revolutions at speed of (30-33) rpm, 18 samples were prepared. The cantabro abrasion test for un-aged compacted mixture, was maintained at the test temperature (25 °C) for at least 6 hours. The average abrasion loss for set of samples should not exceed 20 \%. For second condition accelerated laboratory aging was used to simulate the samples that were
prepared at lab and taken to field. The compacted samples were placed in a forced draft oven set at 60 °C (140 °F) for 168 hr. (7days), then, the samples were cooled to 25 °C (77 °F) and stored for 4 hour before implementation the cantabro test. The average abrasion loss for set of samples should not exceed 30 %. Figure 4 illustrates specimens (Before and After Test). The result of the test was determined by using the following equation.

\[ P = \left( \frac{P_1 - P_2}{P_1} \right) \times 100 \]

*Where* \( P = \) cantabro abrasion loss %.

\( P_1 = \) initial weight of the sample gm.

\( P_2 = \) final weight of the sample gm.

**Figure 4.** Specimen Before and After Abrasion Loss Test

### 4.5 Draindown Test

Draindown features of an un-compacted asphalt mixture were evaluated using basket drainage. The draindown test is performed to evaluate the draining of asphalt binder or fine aggregate from the loose mixture samples under increased temperature. The loose un-compacted mix was taken and transferred...
to the drainage basket and, assembly were placed into the oven at 170 °C for 1 hour ± 5 min. Pre weighed plate was kept below the drainage basket to collect the drained out binder drippings as shown in Figure 5, the percent of material that drainage had been calculated by using the following equation. The maximum allowable draindown shouldn’t exceed 0.3 % accordance with (ASTM D6390-99), 18 samples were prepared.

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

**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.
- D = mass of the catch plate plus drained material gm.

**Figure 5. Asphalt Draindown Test**

### 4.6 Permeability

Permeability is the most influencing factor affecting the durability and long term performance/functionality of OGFC pavement. Two different methods can be carried out to determined permeability in asphalt mixture, namely "constant head" or "falling-head" tests. In this research, falling-head test apparatus was used to determine the rate of flow water that conducted through Marshall specimen, with 150 mm diameter and 150 mm height at optimum asphalt content; according to the Florida Department of Transportation Designation FDOT (FM 5-565/15). 18 samples were prepared, and each sample was tested a minimum of 3 times and the average was determined, figure 6 and 7 show apparatus and prepared samples, respectively. The coefficient of coefficient permeability (K) of the compacted asphalt mixture was calculated depending on "Darcy law", using the succeeding equation.

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

**Where:**
- k = coefficient of permeability cm/sec.
- 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 sec.
- h1 = hydraulic head on specimen at time t1 cm.
- h2 = hydraulic head on specimen at time t2 cm.
- ln = natural logarithmic function. tc = temperature correction for viscosity of water.
5. Determination of Optimum Asphalt Binder Content
According to (ASTM D7064−13) several Marshall specimens were prepared at various asphalt contents from (4 to 6) % (by weight of total mix.) with increment of (0.5) %, (150 samples were prepared). In order to determine the optimum asphalt content OAC %, a series of tests such as cantabro abrasion test (aging and un-aging), draindown test, air void content and permeability were carried out for selecting the optimum asphalt content (OAC) for mixture. The average percentage of asphalt was taken according to these four criteria.

6. Indirect Tensile Strength Test (ITS)
ITS test was vastly utilized to conclude the relative quality and strength of hot asphalt mixtures (HMA), and test was accompanied according to the (ASTM D6931−12) processes by means of the Marshall loading device. Figure 8 shows details of indirect tensile test. A vertical compressive load was applied until the maximum load was extended, the maximum cargo was recorded (peak load at failure). Three specimens for each mixture were tested and the average results were reported. ITS was calculated using the following equation:

\[
\text{ITS} = \frac{2000 \times P}{\pi \times t \times D}
\]

Where: ITS = indirect tensile strength kPa. P = maximum load to failure N. D = diameter of specimen mm. t = thickness of specimen immediately before test mm.

7. Moisture Susceptibility
This test method covers the variation of diametrical tensile strength resulting from the effects of water saturation and accelerated water condition with freeze /thaw cycle of compacted asphalt mixture. Traffic loading and climatic conditions may cause tensile stresses that established within the asphalt pavement and results two kinds of cracks may be demonstrated, called fatigue cracking and thermal or
shrinkage cracking, respectively. (AASHTO T283-14) used to estimate moisture susceptibility of OGFC asphalt mixture. Two subsets of test specimens were produced. Specimens were compacted in Marshall hammer. One subset of 3 specimens was tested in a dry situation. The other subset of the 3 specimens was considered wet situation. Subset subjected to vacuum saturation followed by a freeze cycle at minimum 16 hrs. at -18°C followed by a 24 hour thaw cycle at 24 hrs. at 60°C, after conditioning both subsets were tested for indirect tensile strength An average value of ITS for dry set (Sd) and for wet (Sw) were computed. This was achieved by tester machine head by applying the load to the specimen with a constant rate 50.8 mm / minute (2in/min) the max load at failure was recorded. Figure shows apparatuses and samples prepared with minimum tensile strength ratio of 80 %. The following equation was used to compute the indirect tensile strength ratio (TSR).

\[
\text{TSR} = \frac{\text{Sw}}{\text{Sd}} \times 100
\]

Where: TSR= indirect tensile strength ratio, %. \(\text{Sd} = \) average of indirect tensile strength of dry unconditioned, Kpa. 
\(\text{Sw} = \) average of indirect tensile strength of wet conditioned, Kpa.

Figure 8. Apparatuses and Samples Prepared for TSR Test

8. Test Results and Discussion
8.1 Selection of Optimum Asphalt Content
Once the design gradation was resolved, then numerous specimens were prepared at several asphalt percent in order to regulate the optimum asphalt content. Five asphalt percent were estimated (4, 4.5, 5, 5.5 and 6) %. The specimens were estimated based on air void analysis, cantabro abrasion loss (un-aging and aging), draindown test and permeability. The outcomes for each were exploited to determine the optimum asphalt content (5.6) %. Figure 9 and Table 5 show that.
effect of original asphalt binder content on air void

effect of original asphalt binder content on draindown

effect of original asphalt binder content on abrasion aged

effect of original asphalt binder content on abrasion un-aged

effect of original asphalt binder content on permeability

Table 5. Experimental Tests Results of Marshall Specimen to Find Optimum Asphalt Content (NMAS 9.5 mm).

| AC % | Air Void % | Draindown % | Abrasion Un-aging % | Abrasion Aging % | Permeability m/day |
|------|------------|-------------|---------------------|------------------|--------------------|
| 4.0  | 21.86      | 0.11        | 29.37               | 40.17            | 487.43             |
| 4.5  | 20.79      | 0.13        | 20.85               | 31.21            | 419.68             |
| 5.0  | 19.72      | 0.17        | 18.74               | 26.04            | 370.11             |
| 5.5  | 18.68      | 0.21        | 15.86               | 21.44            | 329.08             |
| **5.6** | **18.60** | **0.22** | **15.00**           | **20.60**        | **326.00**         |
| 6.0  | 18.10      | 0.25        | 14.35               | 19.58            | 296.15             |

8.2 Evaluation of Moisture Sensitivity
Figure 12 demonstrates the mean tablet diagram of indirect tensile strength ratio (TSR) for OGFC (original and modified) asphalt mixture. The result indicates that when asphalt content was increased the TSR increases for both asphalt. Based on the test results, this was due to excessive asphalt content that increases the thickness of asphalt coating. On the other hand, the use of modified asphalt leads to improved moisture susceptibility (TSR), it is recommended to use 4 \% SBS in open graded asphalt mixtures because it provides resistance to moisture damage and exhibit highest (TSR) with (18.5, 16.4 and 13.7) \% increases as compared with original asphalt, at asphalt content (5.1, 5.6 and 6) \%, respectively, SBS increases adhesion between the asphalt and aggregates and decreases the attraction between water and pavement, subsequently, it also improves hot mix asphalt properties. Figures 10 and 11 illustrate the results of ITS for both condition used original and modified asphalt.

![Figure 10. Effect of Modified Asphalt Binder Content on ITS 25°C.](image)

![Figure 11. Effect of Modified Asphalt Binder Content on ITS 60°C After 24 hr. (freeze/thaw)](image)
9. Conclusion

It is evident that all dry condition specimens exhibit higher ITS as compared to wet condition specimens. ITS values have increased with asphalt content increases as compared with optimum asphalt content 5.6 % by (10 and 6.3) % for dry condition and (15 and 9.5) % for wet condition at original and modified asphalt percent (6.1 %), respectively. On the contrary the results showed a decline in value of ITS test. However, this increase has instigated a reduction in air voids content which resulted in reduced abrasion loss and permeability %, while asphalt draindown increased. Test results indicate that the TSR is improved by using polymer-modified asphalt with (4) % SBS instead of unmodified asphalt binder which increases moisture damage resistance (mixture resistance to high temperatures) and exhibits highest (TSR) with (18.5, 16.4 and 13.7)% increases as compared with original asphalt at asphalt content (5.1, 5.6 and 6.1) %, respectively. Also, asphalt modifiers can assist in promoting adhesion between the asphalt binder and the aggregate, thus improving the mixture stiffness.

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