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Assessing the Marshall Properties of Porous Asphalt Concrete

Ghaidaa Abdl Wahab Majeed *
MSc student
College of Engineering
University of Baghdad
Iraq-Baghdad
ghaidaawahab@coeng.uobaghdad.edu.iq

Prof. Saad Issa Sarsam
Professor
College of Engineering
University of Baghdad
Iraq-Baghdad
saadisasarsam@coeng.uobaghdad.edu.iq

ABSTRACT

Porous asphalt paving is a modern design method that differs from the usual asphalt pavements' traditional designs. The difference is that the design structure of porous pavements allows the free passage of fluids through their layers, which controls or reduces the amount of runoff or water accumulated in the area by allowing the flow of rain and surface runoff. The cross-structure of this type of paving works as a suitable method for managing rainwater and representing groundwater recharge. The overall benefits of porous asphalt pavements include environmental services and safety features, including controlling the build-up of contaminated metals on the road surface, rainwater management, resistance to slipping accidents, reduced splashing, and spraying pedestrians and drivers.

In this study, the porous mixture's volumetric and physical properties were tested, and the use of carbon fibers as a type of mixture improver. The results were compared after performing the following steps: Selecting the best gradient for the porous asphalt mixture by selecting the largest proportion of air voids from three gradations group according to specifications **(ASTM 7064),** then choosing the optimum asphalt ratio according to the standard specifications, which are the value of drain down % and the Cantabro abrasion loss % value, as well as the ratio of air voids. After obtaining the optimum asphalt ratio, samples of the asphalt mixture were prepared. Carbon fibers were added to it at a rate of (0.3%) by weight of the total mix and a length of (2 cm) and prepared samples without additives. They were tested by a Marshall device to calculate the stability and flow value and show the effects of fibers on porous asphalt concrete properties. An increase in the stability value and a decrease in the flow and reduction in the drain down rate during exposure to high temperature were observed for the samples containing carbon fibers, by 48.8%, 44%, and 72%, respectively

Keywords: Porous asphalt, Volumetric Properties, Carbon fiber, Drain down, Abrasion loss.

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*Corresponding author
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تقييم خصائص مارشال لخرسانة الأسفلت المسامية

غيداء عبد الوهاب مجيد
طالب ماجستير
جامعة بغداد – كلية الهندسة – قسم الهندسة المدنية

أ. سعد عيسى سرسم
أستاذ
جامعة بغداد – كلية الهندسة – قسم الهندسة المدنية

الخلاصة

رصف الأسفلت المسامي هو أسلوب تصميم حديث يختلف عن التصميمات التقليدية لأرصفة الإسفلت المعتادة حيث يكون الاختلاف هو أن الهيكل التصميمي للأرصفة المسامية يسمح بالمرور الحر للسوائل عبر طبقاتها مما يتحكم أو يقلل من كمية الجريان السطحي أو الماء المتراكمة في المنطقة عن طريق السماح بتدفق الأمطار وكذلك الجريان السطحي. يعمل الهيكل المتقاطع لهذا النوع من الرصف كطريقة جيدة لإدارة مياه الأمطار ويمثل أيضًا إعادة تغذية المياه الجوفية. تشمل الفوائد الإجمالية لأرصفة الإسفلت المسامية كلاً من الفوائد البيئية وخصائص السلامة بما في ذلك التحكم في تراكم المعادن الملوثة على سطح الطريق ، وإدارة مياه الأمطار ، ومقاومة حوادث الانزلاق ، وتقليل تناثر المياه والرش للمشاة والسائقين.

في هذا التقييم ، تم اختبار الخصائص الحجمية والفيزيائية للخليط المسامي واستخدام ألياف الكربون كنوع من محسنات الخليط. تمت مقارنة النتائج بعد تنفيذ الخطوات التالية: اختيار أفضل تدرج لخليط الإسفلت المسامي باختيار أكبر نسبة من الفراغات الهوائية من مجموعة التدرجات الثلاثة وفقًا للمواصفات (ASTM 7064) ثم اختيار نسبة الإسفلت المثلى وفقًا للمواصفات القياسية ، وهي قيمةDraindown ٪ وقيمة٪ خسارة التآكل canabro ، وكذلك نسبة الفراغات الهوائية ، وبعد الحصول على نسبة الإسفلت المثلى ، تم تحضير عينات من خليط الإسفلت وأضيفت إليه ألياف الكربون بنسبة (0.3٪) بوزن الخليط الكلي وبطول (2 سم) وعينات محضرة بدون إضافات ، ثم تم اختبارها بجهاز مارشال لحساب الثبات وقيمة التدفق ولإظهار تأثير الألياف على خواص الخرسانة الإسفلتية المسامية. حيث لوحظ زيادة في قيمة الثبات وانخفاض في التدفق وانخفاض في معدل التصريف أثناء التعرض لدرجة حرارة عالية للعينات المحتوية على ألياف الكربون ، بنسبة 48.8٪ ، 44٪ ، 72٪ على التوالي.

الكلمات الرئيسية: اسفلت مسامي ، الخصائص الحجمية، الياف الكاربون، استنزاف ، فقدان التآكل.

1. INTRODUCTION

Sustainable urban drainage pavements (SUDP) are defined as structures that mimic the earth's surface drainage pattern. The applied porous pavement systems (PPSs) are one of the complete sustainable drainage systems. They have attracted attention for many years to provide environmental balance and carry heavy loads on vehicles. This paving offers a space for flow, allowing fluids to seep through its structure **(Thevis et al.,2016).** It was mentioned that the water leaking from the layers of these porous pavements could be used for non-potable purposes such as car washing and cleaning. These pavements' advantages include reduced tire noise, water splashes, and anti-slip and reduced water build-up damage on the road surface **(Gupta, Rodriguez-Herna 2019)**. The porous pavement's open structure provides better resistance to the slip agent, thus more safety for road users. By replacing traditional sidewalks with this sidewalk, the number of wet weather accidents can be reduced by more than 75% **(Nuruzzaman, 2015).** This porous structure consists of a significant proportion of coarse aggregate with less proportion of fine aggregate and filler. The ratio of voids formed by this structure ranges from more than 15% and less than 25% to create a permeable system that allows liquids to flow. There is stone-to-stone contact, which results in higher air content compared to dense gradient mixtures. Thus, due to the presence of this large percentage of voids, this type is subject to environmental factors and premature aging much faster than usual paving (**WAPA, 2015)**. Drainage is at the forefront of the defects faced by porous paving at high temperatures. Asphalt runoff causes gaps to clog, disrupting fluid drainage, reducing noise, and preventing stagnant water damage. Some researchers have also recommended the use of an improver such as fiber to reduce bond flow. The blockage rate in pavement voids depends on the type of material used in paving, such as cement, concrete, or asphalt, the slope of the pavement, necessary maintenance, environmental conditions, etc., different vehicle loads, and precipitation intensity. Adding durability-enhancing materials in mixtures, especially fibers, is a relatively new idea in porous pavements, and the type of binder is an essential factor. The type of permeable paving has to look for ways to improve its quality by incorporating some additives (**Basel. 2019**). Certain additives such as nano silicate have been shown to improve the abrasion resistance of porous pavements. Natural fibers such as cellulose are among the fibers most used in these open structures because they improve the adhesion stability to resist cracking at low temperatures. Carbon fibers are an enhancer for fluid drainage in porous pavements because they absorb free liquid in the mixture, which effectively contributes to getting rid of gaps clogged during high temperatures (**Sikora et al., 2015**). To enhance some properties such as resilient modulus (M.R.), indirect tensile strength (ITS), synthetic fibers have shown promising results. In general, a large proportion of coarse aggregate and a few fine aggregate proportions should be used in the P.A. mixture to provide a high percentage of voids **(Schaus Ls, 2007)**. The aim of the study is to assess the characteristics of Marshall on porous asphalt mixture with the use of carbon fiber as a kind of mixture improver

2.<u>Materials and Test Methods</u>

2.1 Asphalt

One type of petroleum asphalt, (40-50) penetration grade from Doura refinery, was used. The physical properties and necessary tests of these binder types are shown in **Table 1**. All test results meet the Iraqi specifications **(SCRB R / 9, 2003).**

Table 1. Physical Properties of Asphalt Cement.

Test of Asphalt	**Units**	**ASTM-Designation No.**	**Results**	**SCRB R/9, 2003 Specification**
Penetration; (25 C, 100 gm, 5sec)	(1/10) mm	D5	41	40:50
Softening Point; (Ring & Ball)	C	D36	51	-----
Specific Gravity ; 25℃	-	D70	1,042	-----
Ductility ;(25℃, 5cm/min)	(cm)	D113	162	>(100)
Flash Point (Cleveland Open Cup)	℃	D92	309	>(232)
After (Thin-Film Oven) Test ASTM D 1754				
Retained Penetration Original	(%)	D5	61	55 min
Ductility; (25℃, 5cm/min)	(cm)	D113	89	> (25)

2.2. Coarse Aggregate

Aggregates are used in this work from one of the hot mixing plants in Baghdad Municipality. The sizes of coarse aggregates range from 3/4 inch (19 mm) to No. 4 (4.75 mm). For the sizes of fine aggregates, between No. 4 to No. 200, as is well defined in the requirements of the standard approved in **ASTM** (**7064)**. The aggregates are sifted and combined to prepare the selected gradient to produce an identical and controlled gradient. The physical properties of the coarse aggregates are shown in **Table 2.**

Table 2. Physical Properties of Coarse Aggregate.

Property	ASTM Designation No.	Coarse Aggregate	SCRB R/9, 2003 Specification
(Bulk Specific Gravity)	C127	2.6	-------
(Apparent Specific Gravity)	C127	2.608	-------
(Percent Water Absorption %)	C127	0.57	-------
(Abrasion Los %)	C131	13.08	(30) Max

2.3. Fine Aggregate

Fine aggregate (crushed) is also brought from the same source as coarse aggregate. It contains solid grains and is free from harmful amounts of clay, parasites, and other harmful substances. The fine aggregate gradient ranges from No. 4 (4.75 mm) to No. 200 (0.075 mm). The physical properties of fine aggregates are listed in **Table 3.**

Table 3. Physical Properties of Fine Aggregate.

Property	ASTM Designation; No	Fine Aggregate	SCRB R/9-2003 Specification
(Specific Gravity of Bulk)	C128	2.604	-------
Specific Gravity (Apparent)	C128	2.664	-------
(Percent Absorption of Water %)	C128	1.419	-------

2.4 Mineral Filler

To improve the properties of the asphalt mixture, a mineral filler is used. Its advantages are increasing the mix's viscosity, reducing the percentage of plasticity, and reducing the asphalt mixture's scalability; therefore, it is a significant and essential part of the mixture completion process. The physical properties of the filler used are listed in Table 4 below.

Table 4. Physical Properties of Limestone Dust.

Property	Result
(% Passing sieve No 200)	99
(Specific Gravity of Bulk)	2.67

2.5 Carbon Fibers

Carbon fiber is an improved additive in this work with a percentage **(0.3%)** by mixture weight (**ASTM7064)** and length **(2 cm).** These fibers were obtained using a paper shredder machine in **Table 5** and **Fig. 1**, previously made on carbon fibers.

Table 5. Physical characteristics of carbon fibers.

Test Properties	Typical Value
Nominal thickness- (mm)	0.167
Length of Fiber -(mm)	Can be produced any length
Color of fiber	Dark Black
(Density gm/cm3)	1.82
Tensile Strength- (N/mm2)	40000
Elongation-at-Break %	1.7
Tensile Modulus of elasticity; (K.N./mm2)	225
Base	Polyacrylonitrile
(Temperature of Carbonization)	1400 C o

Figure 1. Implemented carbon fibers.

3. Selection of Aggregate and Gradations

According to the specifications **(ASTM7064)**, the maximum nominal size of aggregates is 12.5 mm. The specified overall gradient appears in **Table 6.** three gradients were chosen from these ranges that can be combated with the international ASTM specifications to determine the most appropriate and desired gradient.

Table 6 Gradation analysis for three options for Wearing Course.

Sieve Size (mm)	**% Passing**		
	Option I	**Option II**	**Option III**
19	100	100	100
12.5	85	92.5	100
9.5	35	47.5	60
4.75	10	17.5	25
2.36	5	7.5	10
0.075	2	3	4

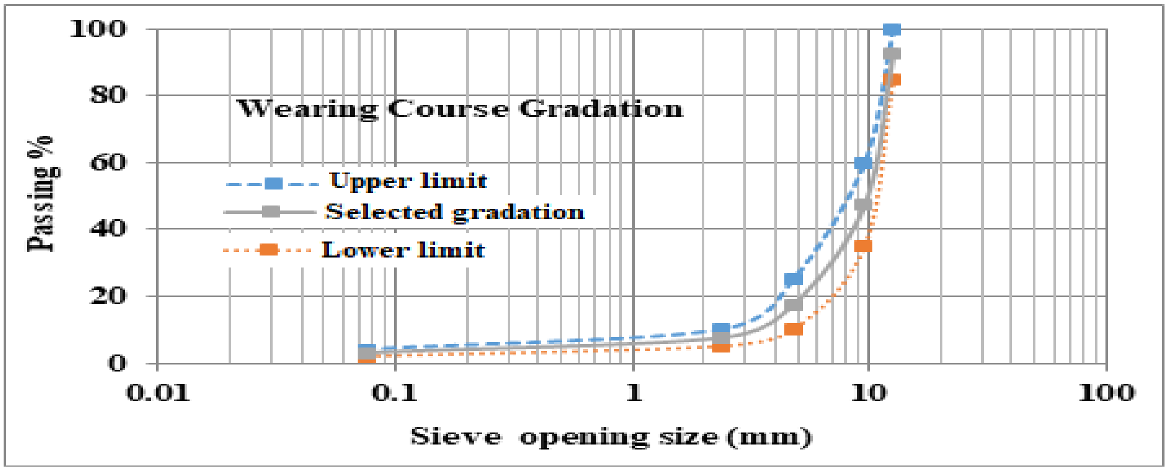


Figure 2. Selected gradation for wearing course (ASTM7064).

4. Testing Program

4.1 Blending of Aggregates

In asphalt mixing designs for roads, mixing more than one aggregate type with different gradients is considered an essential step to produce any good asphalt mixture. For this purpose, five different sizes of aggregate types were mixed in different proportions until the acceptable limits were reached for gradations of aggregates used for porous asphalt by (**ASTM 7064)** specifications. Three grades were defined within the approved ASTM standard, which is: minimum, medium limit, and the third gradient is the upper limit. For the overall success rate.

4.2 Preparation of Porous Asphalt Concrete Mixture

At first, the aggregates are screened, then the aggregates are washed and dried in the oven at 110 degrees to obtain a constant weight. Then the types of aggregates that will be used according to the specifications (coarse and fine aggregate with mineral filler) are mixed and meet the gradient specified in Section 3. After that, the oven's preparation is heated to 160°C so that the graded aggregate is heated before mixing it with the asphalt cement. The asphalt was also heated in the furnace to (150°C) to obtain a kinematic viscosity of (170 ± 20) fork. After that, the prescribed quantities of aggregate and asphalt are mixed well for several minutes to ensure adequate coverage of all aggregates using a spatula. In carbon fiber models, the fibers are cut to the specified length of 2 cm and weighs 0.3% of the mixture's total weight. Then it is added to the aggregates to be heated together. After heating, the same process performed for the unmodified models is repeated.

4.3 Preparation of Marshall Specimens

It is a cylindrical specimen with a diameter of 4 inches (102 mm) and 63.5 mm (2.5 ± 0.05) inches. The Marshall Mold, spoon, and pressure hammer were heated to a temperature (140°C) on a hot plate. A piece of non-absorbent paper was cut according to the template's dimensions under the mold, and then the mixture was poured. The asphalt mixture was placed in a hot mold and then arranged inside the mold using a thinly heated spatula 15 times around the perimeter and ten times around the inside to prevent the mixture from accumulating in one place. Another piece of non-absorbent paper was placed over the mix, and the temperature of the mixture was immediately before the compaction temperature (150 ° C). A template was put on the pressure base, and 75 strokes were placed on each face of the specimen with a specific pressure hammer weighing 4,535 kg and a free fall of 457.2 mm (18 in). The sample is left to cool at room temperature for 24 hours and then extracted from the mold using a mechanical lift. **Fig. 3**. shows some prepared samples

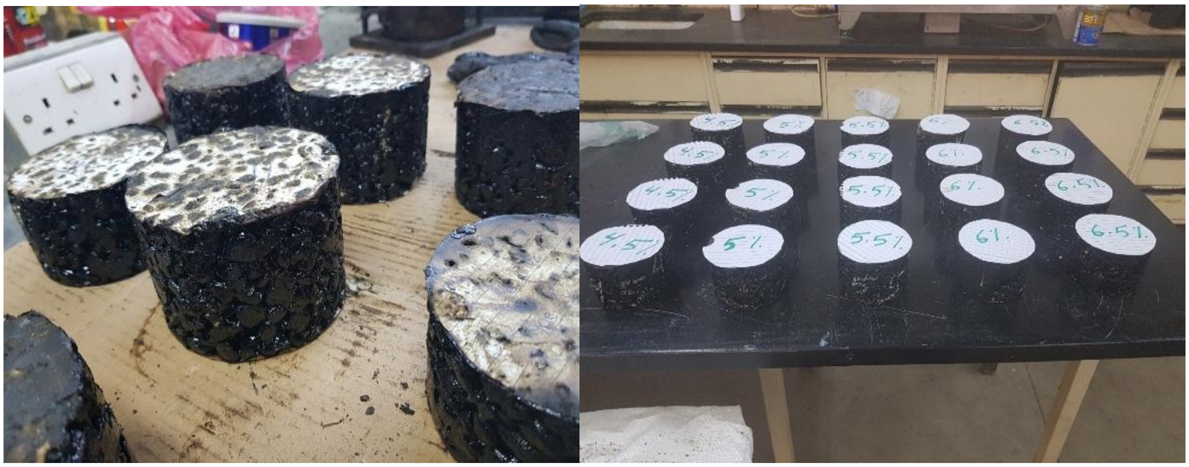


Figure 3. A group of Prepared Specimens.

4.4 Determination of the Most Suitable and Desired Gradation

According to **ASTM D7064/D7064M – 08**, twelve porous asphalt samples (4 samples for each gradation) were produced at this stage with a trail asphalt content of **6%** by the Marshall Method. The purpose of making four samples from each gradation was to compact three of them using 75 blows at each side and then calculate the Bulk Dry Specific Gravity for each one (Gmb), and the fourth sample was not compacted and was used to find (Gmm). After that, percent air voids (Va) for each asphalt mix was calculated using equation 1.

$$Va = 100\,(1 - Gmb\,/\,Gmm) \quad (1)$$

Where:
Gmm = Maximum Theoretical Specific Gravity.
Gmb = Bulk Dry Specific Gravity.
Va = Air Voids Content %.

After finding three values for percent air voids (Va), the asphalt mix with the highest Va was chosen as the most suitable and desired gradation. The calculations mentioned above are listed in **Table 7.**

Table 7. Total air voids calculations for the option **I, II, III** of porous asphalt.

Gradation	**(Gmb) (Average)**	**(Gmm)**	**(Va%) (Average)**
Option I	2.078	2.412	13.8
Option II	2.018	2.428	16.9
Option III	2.050	2.401	14.6

Based on the results above, it is clearly shown that Gradation II is the option that gives the highest voids ratio **(16.9 %).** Accordingly, this gradation shown in **Table 7 (Gradation II)** is considered as the most suitable and desired gradation

5. Determination of Air Voids

After preparing 30 samples of porous asphalt with five different bitumen contents, the total air voids for each bitumen content were determined using the same procedure used in section 4.4 of this research. The results of this step are shown in **Table 8**.

Table 8. Total air void ratios (Va %) for five different bitumen contents in P.A.

Description	**Va (%) (Average of 3 Samples**	**Bitumen Content**
Total Percent of Air Voids (Va %)	18.900	4.5
	18.400	5
	17.600	5.5
	16.900	6
	16.000	6.5

6. Drain down Test

This test was performed based on the specifications of (**ASTM D 6390)** to determine the amount of material that separates itself from the sample at high temperatures and before the compaction work as a whole, where the non-pressurized mixture is placed inside the wire basket (mesh size 6.3 mm) in an oven temperature of 175°C. The discharged materials can be either asphalt binder or a mixture of asphalt bond, additives, or fine aggregate. The test was performed on one out of six samples in each bitumen content for one hour. **Fig. 4** shows the test method, and **Table 9** shows the result of drain down test, according to the following equation:

$$\text{Drain down} = [(D-C) / (B-A)] * 100 \qquad (2)$$

Where:
A = Weight of the empty net (basket) (g).
B = weight of the net (basket) and sample (g).
C = weight of the empty catch plate (g).
D = weight of the catch plate plus drained material (g).

Table 9. Drain down values for five different bitumen contents in P.A.

Bitumen Content %	Drain down Value %
4.5	0.084
5	0.170
5.5	0.510
6	1.020
6.5	1.800

Figure 4. Drain down test.

7. The Cantabro Abrasion Test

This test was performed based on (**ASTM C131)** specifications to determine the abrasion loss of porous asphalt samples. The test was performed on three unaged compacted samples out of six samples in each bitumen content. **Fig. 5** shows the samples after the test, and **Table 10** summarizes the results of this test:

$$\text{Abrasion Loss (P\%)} = [(P1 - P2)/P1] * 100 \qquad (3)$$

where:

P1= Mass of the sample before entering the abrasion machine (g)

P2= Mass of the sample after entering the abrasion machine (g)

Table 10. Cantabro abrasion loss values for five different bitumen contents in P.A.

Bitumen content	Abrasion Loss (P%) (Average)
4.5	70%
5	60%
5.5	50%
6	48%
6.5	41%

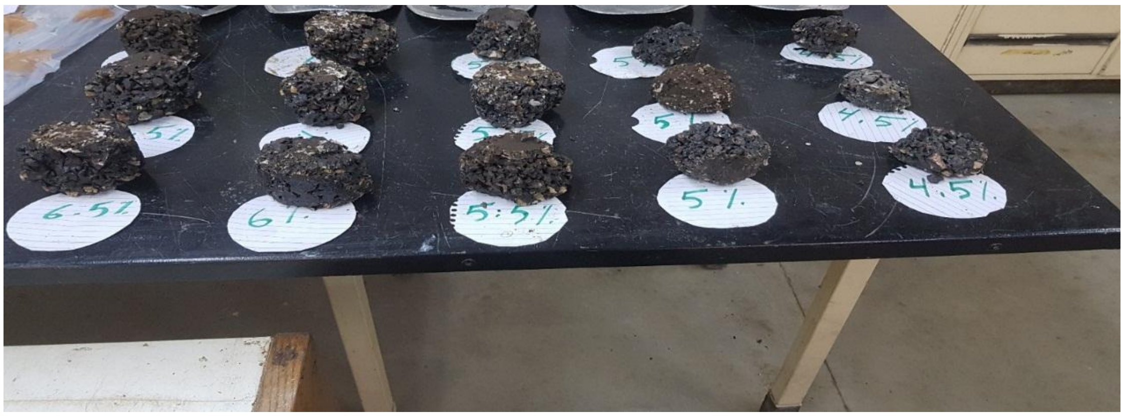


Figure 5. Specimens after Cantabro Abrasion Loss test.

8. Determination of Optimum Asphalt Binder Content

After determining the desired aggregate gradations, this gradation was selected to produce a new thirty (30) porous asphalt samples to determine (optimum asphalt binder content) used in porous asphalt. A trail bitumen contents were selected to produce these samples, starting from 4.5% to 6.5 % with 0.5% bitumen content as an increment. Six asphalt samples were made for each asphalt content. Then some tests were performed in the laboratory on these samples to determine the optimum asphalt binder content, such as: Drain down Test 175C, Cantabro Abrasion Test 25C in addition to calculating the percent air voids (Va) for each asphalt mix from Eq. (1), after finding Gmb and Gmm of the produced samples. The results of this stage are illustrated minutely in sections 5,6, and 7 of this research. **Fig. 6** demonstrates that the optimum asphalt content is 5.2 % based on air voids and drain down requirements of **(ASTM, 2015)** specification

As stated in **(ASTM D7064),** the selected Open Graded Friction Course (OGFC) should be the one which meets the below specifications:

- Total Air Voids ratio should be a minimum of 18%.
- Drain down value should not exceed a ratio of 0.3%.
- Abrasion Loss value on un-aged specimens from the abrasion loss test should not exceed the rate of 20%. The Cantabro abrasion criteria are optional to be used in judgment as per **(ASTM D7064**) recommendations.

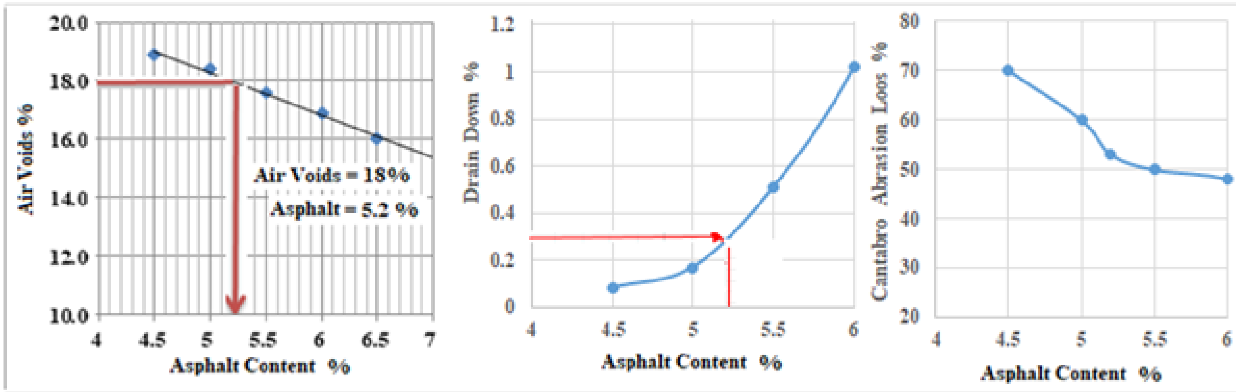


Figure 6. Determination of optimum asphalt content.

9. Tests of Laboratory Evaluation for porous Asphalt Concrete

9.1 Marshall Test Results

This method describes the steps for measuring the sample's plastic flow resistance to the asphalt pavement mixture loaded on the model's side surface. The test is performed by the Marshall instrument shown below in **Figures 7** and **8,** and the test steps **(ASTM D 1559)**. The cylindrical sample was prepared by placing it under 60°C in a water bath for (30) minutes. Then it was inserted into the device between the jaws and pressed until the sample failed and the results were taken and for this test. Three samples were prepared from each type of control mixture (the first mixture without additive and another mixture contains carbon fiber in proportions of 0.3% by weight of the mix)

Figure 7. Marshall Test Device.

Figure 8. Water path.

9.1.1 Effect of Carbon Fiber on Marshall Properties

Because the porous asphalt mixture has a high gaps ratio compared to the usual mixtures, it is subject to oxidation and loss of durability with less time and hence the idea of adding carbon fibers to the mix to study the volumetric properties and the changes that occur on the results of the tests that contribute to improving their permanence on the one hand and the porous property on the other hand.

9.1.2 Stability – Bitumen Content Relationship

Stabilization is defined as the maximum required load to reach the sample's failure when applying the load at a constant rate of 50 mm/min **(Jendia, 2000)**. **Figure 9** displays the stability results for different bitumen ratios with and without fibers; the Marshall test indicated that the mixtures' stability containing fibers was higher than those without. In samples containing carbon fibers, the stability value increases with increasing asphalt content and gradually decreases. These results can be attributed to fiber adhesion and network effects; this trend can be explained as follows: The fibers play the role of a bridge connecting the aggregate grains with the binder material, and when fracture appears in the asphalt mixture, they thus resist the spread of fracture development. The fibers also form spatial networks for stability and strength mix. Therefore, the fibers may not be arranged uniformly, while they clump together to be a weak point in the mixture's composition. As a result, the Marshall stability value decreases at relatively high asphalt contents

9.1.3 Flow – Bitumen Content Relationship

The flow is defined as the quantity of total deformation at a maximum load; **(Jendia, 2000).** and **Figure 9** shows the flow results for different bitumen ratios represented with and without fibers. The flow values in the models with the fiber content are less than the values of the models that are without fibers. This is due to the carbon fibers absorbing the free asphalt in the models, and the value increases by increasing the content of the asphalt.

9.1.4 bulk Density

Results showed that the bulk density of the asphalt mixture increases slightly after adding fibers. The bulk density of the asphalt mixture increases with the increase of asphalt content as shown in **Figure 9,** because carbon fibers replace some air particles in the existing gaps, which helps compress the components more because of the lack of gaps during stacking for 75 strokes per face, and thus an increase in the apparent density of the same size.

9.1.5 Voids in Total Mixture (A.V. %)

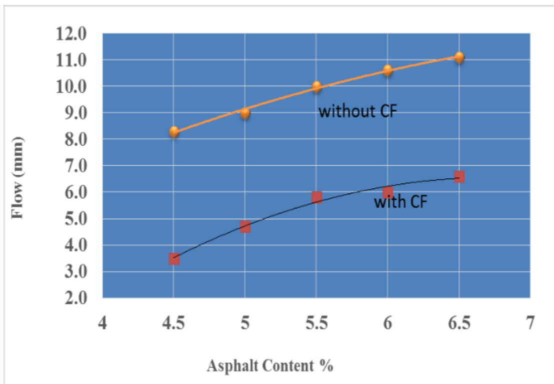
It was noted that the samples made from the fiber contents 0.30% of the weight of the mixture contain a smaller percentage of voids than samples that do not contain carbon fibers, as shown in **Fig.9**, where the fibers act as a bridge to document the connection between them and the aggregates, which gives more surface area To the aggregate, thus breaking the size of the one gap of voids and a decrease in the proportion of total voids. The specification **ASTM 7064** advised that the additive percentage should not exceed the ratio 0.3% by total mix to avoid losing access to the porous mixture.

9.1.6 Voids in the Mineral Aggregate (VMA%)

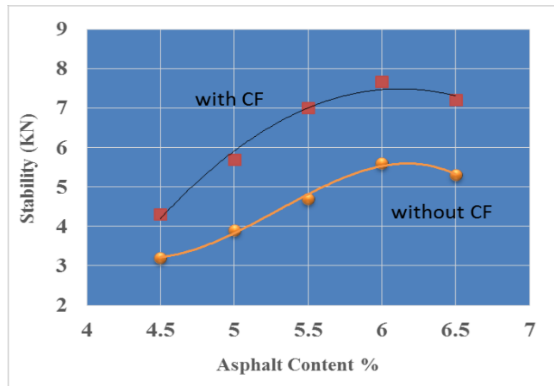
Results are shown regarding the effect of fiber addition on (VMA), as VMA decreases after adding fibers to asphalt mixtures. The increase in bulk density as higher bulk density leads to lower VMA. This characteristic is important for hot zone sidewalks because asphalt is prone to drain down and can prevent further bleeding by providing more space to transfer the adhesive. This may be due to the increase in the surface areas to be coated, as the fibers absorb some of the free bonding material and then lead to a reduction in the voids in the mixture because they act as a bridge between the grains of aggregate, leading to a reduction in the size of air voids between aggregate.

9.1.7 Voids Filled with Asphalt (VFA %)

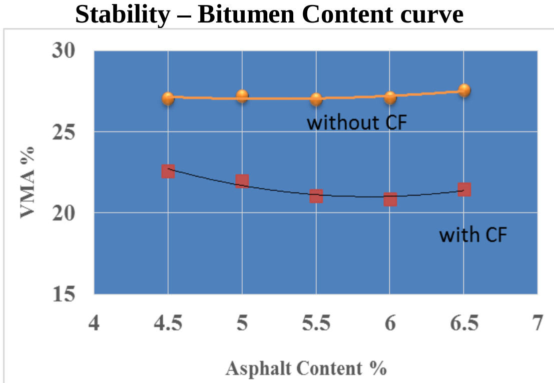
The percentage of (VFA) decreases with the increase of the asphalt content. The decrease in the gaps filled with asphalt VFA indicates a reduction in the thickness of the effective asphalt film between aggregate particles, which results in higher cracking at lower temperatures. Also, the asphalt mixture's lower durability because the asphalt fill and recover effects lead to improved elasticity. (Tapkın, 2008), as shown in **Fig.9**.



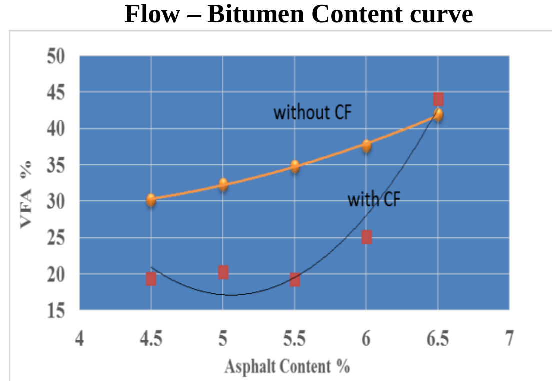
Stability – Bitumen Content curve



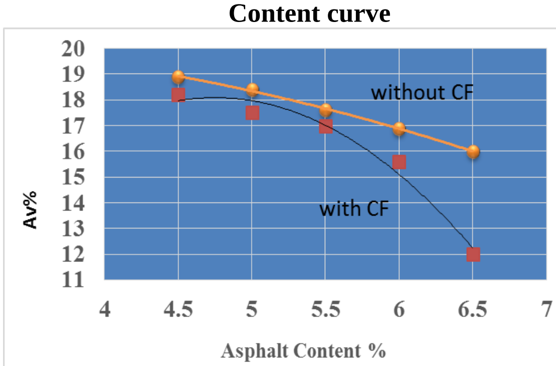
Flow – Bitumen Content curve



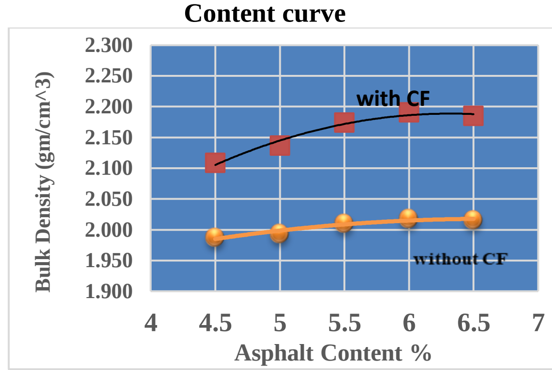
Voids in the Mineral Aggregate– Bitumen Content curve



Voids Filled with Asphalt– Bitumen Content curve



Voids in Total Mixture– Bitumen Content curve



Bulk Density– Bitumen Content curve

Figure 9. Marshall Test Results for porous Asphalt Mixture (without and with carbon fiber).

10. Effect of adding carbon fibers on the drain Down curve

Fig.10 shows the fibers' effect on reducing and controlling the drain down significantly, as the fibers absorb the free asphalt from the mixture. Thus a balance becomes achieved in the amount of asphalt that begins bleeding When temperatures rise. Under the influence of loads, Fibers also penetrate the voids, which leads to a decrease in the volume of voids, which reduces the asphalt leaving and completely closing the gaps. the lowest percentage of drain down is obtained at the rate of asphalt 4.5% At its value 0.055

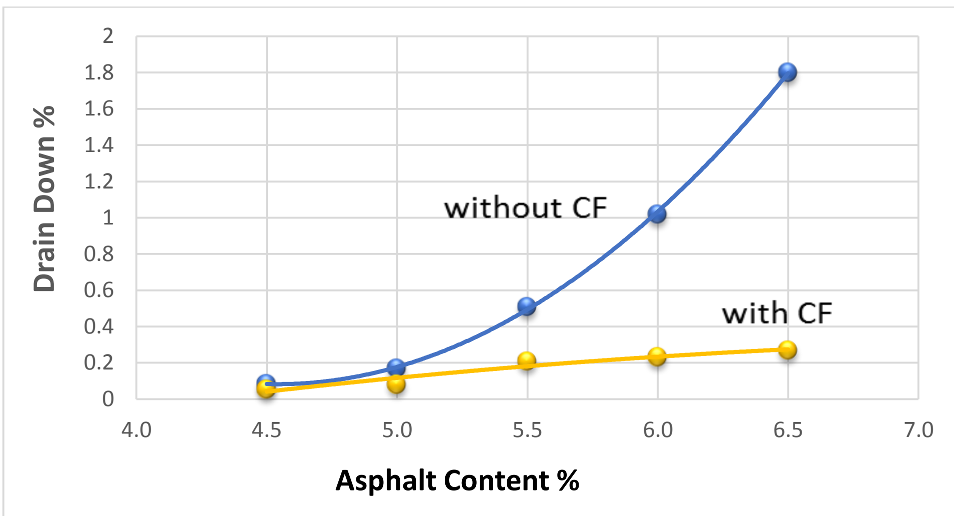


Figure 10. The relationship between the effect of carbon fibers and the percentage of drain down.

11. Effect of adding carbon fibers on the Abrasion loss

From **Fig. 11** below, it is clear that the abrasion ratio decreases by increasing the ratio of asphalt by the possibility of increasing the bond between the aggregate particles. When adding carbon fibers to the mix, they improve bonding and increase the surface area of the aggregate, which reduces abrasion

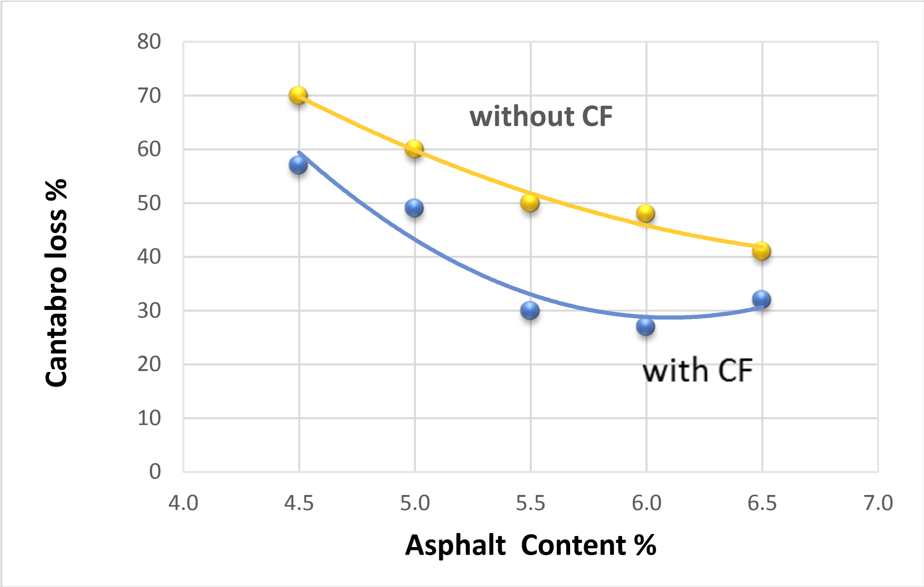


Figure 11. The relationship between carbon fibers and the percentage of abrasion loss.

12. RESULTS AND DISCUSSION

➢ From **Fig. 6** :

- The percentage of air voids decreased when increasing the asphalt content in the mixture, and that the lowest rate of voids allowed in the porous mixture, according to the standard **(ASTM D7064),** corresponds here to **5.2** content of asphalt
- The drain down value is directly proportional to the bitumen value. The higher the bitumen value, the higher the drain down, and the maximum value of 1.8% at 6.5% bitumen content. It can be indicated that when increasing the bitumen value at high temperatures, the asphalt mixture will find an excess fraction of the bitumen to be separated from the sample, thus increasing the drain down value. Also, referring to the specification **(ASTM 7064)**, it was found that the most massive drain down ratio is 0.3%, which corresponds to an asphalt content of **5.2**
- It is clearly shown that the Cantabro abrasion loss value is inversely proportional to the bitumen value. When the bitumen value increased, the abrasion loss decreased until reaching the minimum value of 41 % at 6.5 % bitumen content. This occurred because when bitumen content increased, the asphalt mix's durability will increase, and thus is resistance against abrasion will usually be improved. We also note that all values exceed the permissible value of abrasion. This indicates the need to add some additives or modifiers to the mixture to improve the durability of the porous asphalt mixture.

13. CONCLUSION

Based on what has been achieved and tested above, we can conclude the following points.

1. The results indicated that the Marshall porous mixture's stability increased by 48.8%, while the flow of Marshall decreased by 44% when adding carbon fibers by 0.3% of the weight of the mixture. Due to the high air voids of the porous asphalt compared to thick asphalt concrete, stability values are lower than conventional asphalt. In contrast, reduced flow value is attributed to cementing the mixture with carbon fibers, which effectively reduces flow and makes the mixture more balanced.
2. A decrease in A.V., VMA, and VFB, while the specific gravity increases after adding carbon fibers in the porous asphalt mixture.
3. From the previous results, it clearly appears that 5.2 % of bitumen contents are the optimum content that meets ASTM D7064 specifications in terms of air voids and drain down values
4. Abrasion loss is reduced by 48% after adding carbon fiber to a porous mixture compared to the control mixture.
5. The carbon fiber reduced the drain down rate in the porous mixture during exposure to a high temperature by 72%.

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