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Impact of carbon fibers on permeable asphalt concrete

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ABSTRACT
Porous asphalt concrete which also referred as permeable pavement is the pavement that allows water to infiltrate through its surfaces which could support the skid resistance at heavy rainfall areas. In this investigation, which was carried out during February to April 2020, the influence of incorporating carbon fibers into the porous asphalt concrete surface layer was assessed. Specimens were prepared and tested for voids, indirect tensile strength, drain down, cantabro test and permeability before and after incorporating carbon fibers. It was noted that application of an optimum asphalt content of 5.2 % can meet the voids and drain down requirements. However, the addition of 0.3 % carbon fibers has improved the overall quality of porous asphalt concrete; the tensile strength ratio was increased by 39%. The cantabro abrasion loss and the drain down were reduced by (48 and 72) % respectively after implementation of carbon fibers. On the other hand, the permeability declines by 59.5 % after implementation of carbon fibers as compared to the control mixture.

Keywords: Porous pavement, asphalt concrete, carbon fibers, permeability, drain down, cantabro test

1. INTRODUCTION

Planning for a green transportation infrastructure include the use of porous asphalt concrete in roadway such as a suitable permeable asphalt concrete pavement as an alternative to the traditional dense graded pavement. Putman and Kline, (2012) stated that porous asphalt concrete pavement mixture is usually designed with an open graded aggregate gradation to increase the number of fully permeable air voids, this allows water to penetrate through the voids in a proper drainage process, removing it from the surface of a roadway much faster than traditional dense-graded pavement. The mixture of such pavement surface layer can have a void index ranging between 16% and 22%, to allow proper drainage, (WAPA, 2015). The application of porous pavement is indicated in parking areas and in sections of horizontal curves geometry at heavy rainfall areas, (Elvik and Greibe, 2005). As reported by (Fini et al., 2017), porous pavement allows good drainage of rainwater, reduction of urban heat island effect caused by evaporation, reduction of road traffic noise, control of spray and flash effect and the eliminate of aquaplaning. The influence of the microstructures of pores on anti-clogging performance of porous asphalt concrete was investigated by (Hu et al., 2020). Aggregates with different sizes and shapes are used to prepare specimens. The X-ray CT device was implemented to scan specimens before and after clogging test, and the influence of aggregates on pores was determined. The relationship between anti-clogging performance and pore characteristics has been investigated. It was concluded that the regular shape presents excellent anti-clogging performance. Norhidayah et al., (2019) reported that addition of carbon fibers to asphalt concrete mixture can significantly improve its mechanical properties, improve the performance of asphalt pavement, and prolong the fatigue life of a pavement structure. Kanitpong et al., (2003) studied and quantified the effect of air void content, specimen thickness, aggregate shape, and aggregate gradation on hydraulic conductivity of porous asphalt concrete. The results of the investigation have indicated that air void content is the predominant factor controlling hydraulic conductivity; however, aggregate shape and gradation also have a statistically significant influence. The specimen thickness was not found to be a significant factor affecting hydraulic conductivity of laboratory prepared specimens. James et al., 2017 addressed the distresses commonly seen by adjusting the asphalt and dust content of porous friction course mixes to improve durability. Performance tests were conducted to evaluate the effect of additional filler passing the 0.075 mm on one pavement sections exhibiting good field performance and another that had poor field performance. It was reported that the Cantabro abrasion loss test makes a good indicator of mix performance, and a maximum loss of 20% is recommended. The study revealed the importance of increased percent fines (passing the 0.075 mm sieve) to provide more durable porous friction course mix designs. Qin, 2019 stated that porous friction course has the advantages of improving the riding quality and noise reduction effectiveness. However, it was reported that because of the large voids in the pavement, this could give rise to the asphalt binder more vulnerable to the air, the sun, the rain, and other negative factors. This will cause rapid declines of the binder properties soon and cause the early damage such as loosen and stripping. So, high viscosity asphalt is recommended to enhance the bonding property of the mixture. Birgisson et al. 2006 evaluated the use of open graded friction course in Florida. A falling head permeameter was implemented to measure the hydraulic conductivity of test sections of the porous pavement. Hardiman, 2005 stated that the addition of modified binder may improve the resistance to disintegration of porous asphalt, however, the permeability is lowered slightly as compared to conventional base binder mix. The overall properties of porous asphalt concrete such as permeability, and the resistance to abrasion loss decreases if the maximum size of aggregate in porous asphalt decreases.

2. METHODOLOGY

The aim of the present investigation which was conducted during February to April 2020 is to assess the influence of incorporating carbon fibers into the porous asphalt concrete surface layer. Specimens will be prepared and tested for voids, indirect tensile strength, drain down, cantabro test and permeability before and after incorporating carbon fibers.

Materials properties

The materials used in the present investigation are locally available and widely used in roadway construction.

Asphalt Cement

Penetration grade 40-50 asphalt cement was implemented in this investigation as a binder. It was obtained from Dourah refinery. The important physical properties for this binder are presented in Table 1. It can be noted that test results meet the State Commission of Roads and Bridges (SCRB R/9, 2003) specification.

Table 1. Physical Properties of Asphalt Cement

Test	Units	ASTM, 2015 Designation No.	Result	SCRB R/9, 2003 Specification
Penetration (25oC, 100 gm, 5sec)	(1/10 mm)	D-5	41	40-50
Softening Point (Ring & Ball)	(°C)	D-36	51	-----
Specific Gravity at 25℃	-----	D-70	1.042	-----
Ductility (25℃, 5cm/min)	cm	D-113	162	>100
Flash Point, (Cleveland open Cup)	(°C)	D-92	309	>232
After Thin-Film Oven Test ASTM D 1754				
Retained Penetration of Original	(%)	D-5	61	55 (min)
Ductility (25℃, 5cm/min)	(Cm)	D-113	89	>25

Coarse Aggregate

The crushed coarse aggregates used in this work are obtained from the hot mix plant of Amanat Baghdad at Dourah. The size of coarse aggregate ranged between ¾ inch (19mm) to No.4 (4.75mm) as well-defined in (SCRB, 2003) requirement. The physical properties of the coarse aggregates are listed in Table 2.

Table 2. Physical Properties of Coarse Aggregate

Property	ASTM, 2015 Designation No.	Coarse Aggregate	SCRB R/9, 2003 Specification
Bulk Specific Gravity	C-127	2.6	-------
Apparent Specific Gravity	C-127	2.608	-------
Percent Water Absorption	C-127	0.57	-------
Los Angeles Abrasion loss %	C-131	13.08	30 Max

Fine Aggregate

Fine aggregates (crushed) were collected from the same source of coarse aggregates. It involves hard, tough, grains, free from harmful amount of clay, or other harmful substances. The fine aggregate gradient ranges from the size of sieve No. 4 (4.75 mm) to sieve No.200 (0.075 mm). The physical properties of fine aggregates are shown in Table 3.

Table 3. Physical Properties of Fine Aggregate

Property	ASTM, 2015 Designation No.	Fine Aggregate	SCRB R/9, 2003 Specification
Bulk Specific Gravity	C-128	2.604	-------
Apparent Specific Gravity	C-128	2.664	-------
Percent Water Absorption %	C-128	1.419	-------

Mineral Filler

Mineral Filler is the portion of material passing the sieve No.200 (0.075mm). It is generally utilized to improve mix characteristics throughout increasing viscosity, reducing plasticity, and reducing the volume change. Limestone dust is used in this work as mineral filler. Its source is a lime plant in Karbala governorate. The physical features of the utilized filler are presented in Table 4.

Table 4. Physical Properties of Limestone Dust

Property	Result
% Passing No.200	99
Bulk Specific Gravity	2.67

Carbon Fibers

Carbon Fibers were added at a rate of 0.3% by weight of mixture. The length of the fibers is (2 cm) as demonstrated in Figure1. These fibers were obtained by using a paper shredder machine. The physical properties are shown in Table 5.

Table 5. Physical characteristics of carbon fibers

Test Properties	Typical Value
Nominal thickness (mm)	0.167
Fiber Length (mm)	Can be produce any length
Color	Black
Density gm/cm3	1.82
Tensile Strength (N/mm^2)	40000
Elongation-at-Break, %	1.7
Tensile Modulus of elasticity (KN/mm^2)	225
Base	Polyacrylonitrile
Temperature of Carbonization	1400 °C

Figure 1. Carbon fibers Implemented

Selection of Aggregate and Gradations

According to (ASTMD-7064, 2015) specification, the nominal maximum size of aggregate is 12.5 mm for wearing course. Three aggregate gradation was selected and tried as shown in Table 6. The final adopted gradation is demonstrated in Figure 2.

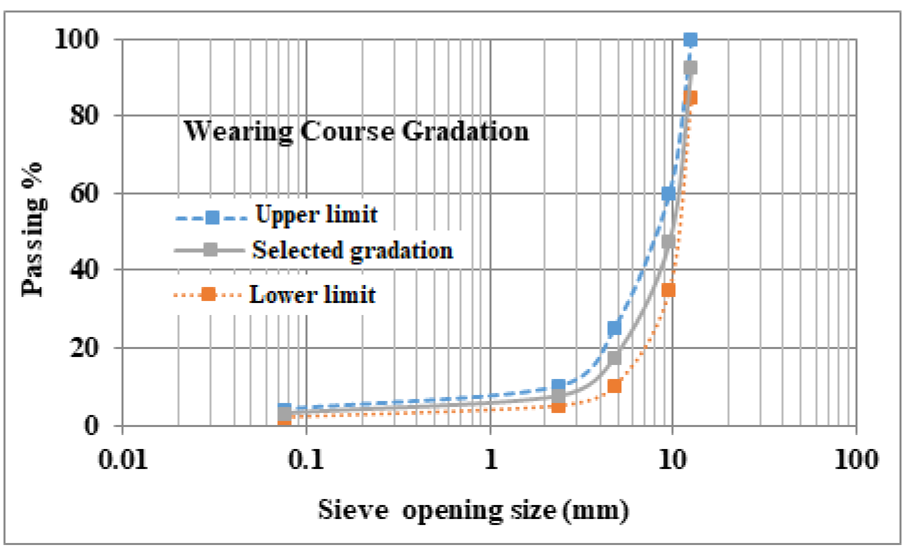

Figure 2. Selected gradation for wearing course

Table 6. Gradation analysis for three options for Wearing Course

Sieve Size (mm)	% Passing			ASTM D-7064, 2015 Specification limits (%)	
	Option I	Option II	Option III	Minimum	Maximum
19	100	100	100	100	100
12.5	85	92.5	100	85	100
9.5	35	47.5	60	35	60
4.75	10	17.5	25	10	25
2.36	5	7.5	10	5	10
0.075	2	3	4	2	4

3. TESTING METHODS

Preparation of porous Asphalt Concrete Mixture

The aggregate was first washed, dried in an oven to a constant weight at 110˚C, and then separated by sieving to different sizes. Coarse and fine aggregates were combined with the required amount of mineral filler to meet the selected gradation. The combined aggregates mixture (coarse, fine and filler) was then heated to (160˚C) in an oven. The asphalt cement was heated to (150˚C) to produce a kinematic viscosity of (170±20) centistokes. Then the desired amount of asphalt binder was added to the heated aggregate, and thoroughly mixed by hand for two minutes using a spatula until all the aggregate particles were covered with thin layer of asphalt cement. In the case of specimens that contain carbon fibers, the carbon fibers are cut to the prescribed length of 2 cm and prepared to have 0.3% of the total asphalt concrete mixture weight. Then it is added to the aggregate before heating and mixed thoroughly.

Preparation of Permeable Asphalt Concrete Specimens

Specimens of 63.5 mm in height and 102 mm in diameter were prepared. Mold, spatula, and compaction hammer were heated to a temperature of (140˚C) on a hot plate. Apiece of non- absorbent paper, cut to size, was placed in the mold bottom prior to the introduction of the mixture. The asphalt mixture was placed in the preheated mold and then vigorously spaded 15 times around the perimeter and 10 times around the inside with a heated spatula. The compaction temperature of mixture was monitored to be within (150˚C). Each specimen was subjected to 75 blows on the top and the bottom applied with specified compaction hammer. The specimens were left overnight in mold cool at room temperature and then it was extracted from the mold with the aid of mechanical jack. Figure 3 exhibit part of the prepared specimens.

Figure 3. Part of the prepared specimens

Determination of the Most Suitable and Desired Gradation

According to (ASTM D-7064, 2015) and D-7064M – 08, twelve porous asphalt concrete mixtures (4 samples for each gradation) were prepared with a trail asphalt content of 6% by the Marshall Method. The purpose of producing four samples from each gradation was to compact three of them using 75blows at each side and then calculate the Bulk Specific Gravity for each one (Gmb) and the fourth mixture was implemented to find the Maximum Theoretical Specific Gravity (Gmm). After that, the percent air voids (Va) for each asphalt mixture was calculated using equation (1).

$Va = 100 (1 – Gmb / Gmm)$ .... Equation (1)

Where:
Va = Air voids %
Gmb = Bulk specific gravity
Gmm = Theoretical Specific Gravity

After obtaining the air voids (Va) content for the three gradation options, the asphalt mix with the highest Va was chosen as the most suitable and desired gradation. Table 7 demonstrates the calculated air voids for each gradation alternative. Similar procedure of selection of desired gradation was followed by (Kline, 2010).

Table 7. Air voids calculated for each gradation alternative

Gradation	Bulk Dry Specific Gravity (Gmb) (Average)	the Maximum Theoretical Specific Gravity (Gmm)	Air Voids Content % (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 which gives the highest voids ratio (16.9 %). Accordingly, the gradation shown in Figure 2 is considered as the most suitable and desired gradation.

Determination of Air Voids

After preparing 30 specimens of porous asphalt concrete with 5 different asphalt contents, the total air voids for each asphalt content group was determined. The results of this step are shown in Table 8.

Table 8. Total air void ratios (Va %) for 5 different asphalt contents

Description	Va (%)(Average of 3 Samples)	Bitumen Content
Total Percent of Air Voids (Va %)	18.9	4.5
	18.4	5
	17.6	5.5
	16.9	6
	16.0	6.5

Draindown Test

This test was performed based on (ASTM D 6390, 2015) specifications to determine the portion of material (in percentage) which separates itself from the sample as a whole and is placed outside the wire basket (No.4 mesh size) during the test. The drained down materials may be either the asphalt binder, or a combination of the asphalt binder, filler, and fine aggregates. The test was performed on one loose sample out of 6 samples for each asphalt content at 175 ° C for one hour. The irregular distribution of binder generated by its draindown can lead to raveling in zones with low binder content, which can reduce the permeability in the zones with accumulated binder. The occurrence of binder draindown through the specimen can reduce the permeability of mix. The drain down % was calculated according to the following equation (2). Table 9 presents the test results. Figure 4 demonstrates the drain down test.

$Draindown = [(D-C) /(B-A)] * 100$ ....Equation (2)

Where:
A = mass of the empty wire basket (g)

B = mass of the wire basket and sample (g)
C = mass of the empty catch plate or container (g)
D = mass of the catch plate or container plus drained material (g)

Table 9. Draindown values for 5 different bitumen contents in PA

Asphalt Content %	Draindown Value %
4.5	0.084
5	0.170
5.5	0.510
6	1.020
6.5	1.800

Figure 4. Drain down test

The Cantabro Abrasion Test

This test was performed based on (ASTM C-131, 2015) specifications to determine the abrasion loss of porous asphalt concrete specimens where the test was performed on 3 specimens for each asphalt content. The test asphalt concrete specimen was placed in the Los Angeles abrasion apparatus drum without any abrasive charges. The Los Angeles machine was operated for 300 revolutions at a speed range of 30–33 revolutions per minute. The material was collected from the drum and the percentage of weight loss in the specimen when compared to its initial weight was expressed as the abrasion loss. The temperature monitored during the test procedure was within a range of (25 ± 2)°C as specified in the (ASTM – 7064, 2015) and the maximum abrasion loss should not exceed 20% . The cantabro abrasion loss is calculated based on equation 3. Table 10 summarizes the results of this test, while Figure 5 exhibit the specimens after cantabro test.

Abrasion Loss (P %) = [(P1-P2)/P1]*100 ....Equation (3)

Where:
P1= Mass of sample before entering the abrasion machine (gm)
P2= Mass of sample after entering the abrasion machine (gm)

Table 10. Cantabro abrasion loss values for 5 different bitumen contents

Bitumen content	Abrasion Loss (Average of three specimens)
4.5	75
5	60
5.5	47
6	39
6.5	32

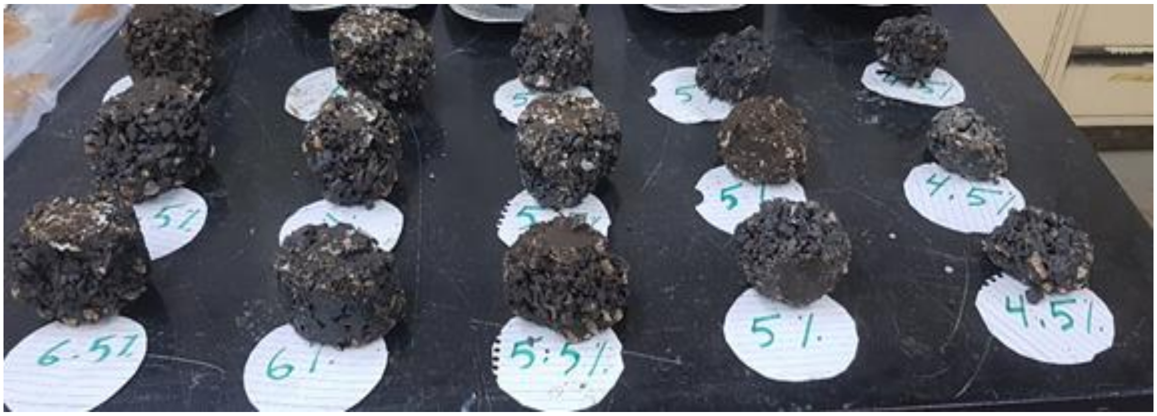

Figure 5. Specimens after cantabro Abrasion Loss test

Determination of Optimum Asphalt Binder Content

To determine the optimum asphalt cement binder content in porous asphalt concrete, 30 specimens were prepared with 5 different asphalt contents starting from 4.5 % to 6.5 % with 0.5 % increment. These asphalt concrete specimens were tested against its resistance to abrasion loss (cantabro test) and drain down in addition to determination the percentage of air voids in each bitumen content. Figure 6 demonstrates that the optimum asphalt content is 5.2 % based on air voids and drain down requirements of (ASTM, 2015) specification. Such findings are in agreement with those reported by (Alvarez et al., 2008).

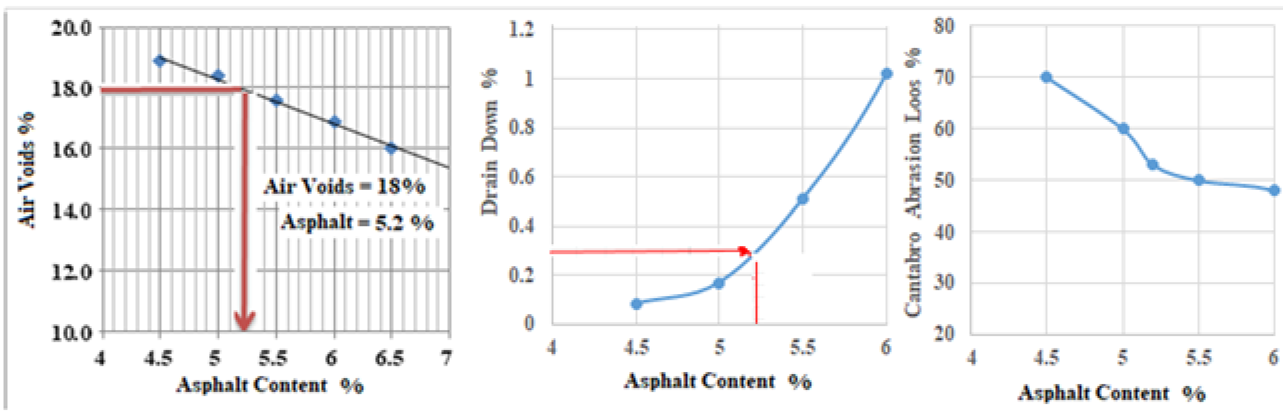

Figure 6. Determination of optimum asphalt content

Moisture susceptibility Measurement of Porous Asphalt Concrete

Knowing the moisture susceptibility of porous asphalt concrete is considered as a vital issue since such type of pavement is designed to be in touch with intensive rainwater flow. The indirect tensile strength test is implemented to determine the tensile properties of asphalt concrete which may be of additional relevance to pavement cracking characteristics. Tensile Strength Ratio (TSR) was used to predict the moisture susceptibility of asphalt concrete mixtures. The recommended limit by (AASHTO, 2013) of (80%) for tensile strength ratio (TSR) was followed to distinguish between moisture susceptible and moisture resistant mixtures. High TSR values indicate that the mixture is expected to perform better and resist moisture damage. Two groups of Porous asphalt concrete specimens of Marshall size were prepared using the optimum asphalt content. The first group was the control mixture at optimum asphalt content tested for Indirect Tensile Strength ITS as per (ASTM D-6931, 2015). The second group was the carbon fiber modified asphalt concrete. The two groups were divided to subsets, the first subset was tested in dry condition while the second subset was subjected to moisture damage as per (ASTM, 2015) specimens were placed in a vacuum glass container filled with distilled water at 25°C to obtain (55 to 80) % degree level of saturation, specimens were then covered with plastic bag and kept in the deep freezer at a temperature of (-18±3) °C for a minimum of 16 hours. Specimens were transferred to the water bath at 25°C for 2 hours after the freeze-thaw cycle, and tested for indirect tensile strength, the test results were denoted as (ITS for moisture-conditioned specimen). The Tensile Strength Ratio TSR refer to the ratio of average indirect tensile strength ITS of the wet (conditioned) subset to the average indirect tensile strength of dry (unconditioned) subset, tested at a temperature of 25 ± 1 °C. ITS (kPa) was calculated using equation 4. However, TSR (%) was calculated using equation 5.

$ITS = 2000\ P\ (ult.) / \pi\ t\ D$ ....Equation (4)

Where

ITS = indirect tensile strength, kPa.
P (ult.) = ultimate applied load required to fail specimen, N.
t = thickness of the specimen, mm.
D = diameter of specimen, mm.

$TSR\ (\%) = [\frac{ITS\ (Conditioned)}{ITS\ (Unconditioned)}] \times 100$ ....Equation (5)

Permeability of Porous Asphalt Concrete

Permeability (K) of porous asphalt concrete is considered as one of the major indicators of its performance throughout its service life. To evaluate the permeability of porous asphalt and the relationship between air void and permeability coefficient (K), the falling head permeability test was adopted. Similar procedure was reported by (Mohammad et al., 2006). After determining the optimum asphalt content, two sample of porous asphalt concrete have been prepared using the optimum binder content. The first sample was the control without carbon fibers while the second one contains 0.3 % of carbon fibers by weight of the mixture. The mixture was compacted inside the steel mold specially prepared for the test to have 102 mm in diameter and 152 mm height using75 blows of Marshall Hammer for each face to the target density. Figure 7 shows the mold assembly implemented for permeability test. Both ends of the sample were waxed with epoxy to ensure that the water did not pass from the edge of the mold. Similar sealing process was conducted by (Bowders et al., 2002).

Figure 7. Permeability test of Porous Asphalt Concrete

Samples and the molds were left for 24 hours at room temperature, then were soaked in a water bath at 20°C to normalize the temperature for two hours. The test was carried out by adding one liter of water (1000 cm^3), and then the time required for run out of this quantity of water was calculated. To evaluate the permeability of porous asphalt concrete mixture, the falling head permeability test was adopted. The test was run three times for each porous asphalt concrete sample. Afterwards, an electric suction pump was attached to the mold and the permeability test was repeated for three times for each sample, and the time taken to drain the 1000 cm^3 of water was measured. The coefficient of permeability was calculated using equation 6.

$K = Q*L / A*H*T$................ Equation (6)

Where:

K: permeability coefficient (cm/second)
Q: Collected Water Volume (cm^3)
L: Sample Height (cm)
A: Cross Sectional Area of Asphalt Sample (cm^2)
H: Water Column Height (cm)
T: Time (second)

4. RESULTS AND DISCUSSION

As stated in (ASTM D-7064, 2015), the selected porous asphalt concrete should be the one which meets the requirements of minimum total air voids of 18%, the drain down value should not exceed 0.3% as per (ASTM C-175, 2015), and the Abrasion loss (cantabro test) should not exceed 20% where the Cantabro abrasion criteria are optional to be used in judgment as per (ASTM D7064, 2015) recommendations. The binder content which fulfils all the requirements is selected as optimum asphalt binder content. If none of the binder contents meet the criteria, then a remedial action becomes necessary which may include the use of stabilizers and modifiers into the mix. The optimum asphalt binder content of 5.2 % meets the requirements of voids and drain down and is considered suitable for porous asphalt concrete.

Influence of Carbon Fibers on Moisture Susceptibility of Porous Asphalt Concrete

Figure8 demonstrates the influence of carbon fibers on the indirect tensile strength while Figure9 exhibit the moisture susceptibility parameters. It can be observed that carbon fibers were able to almost reserve the indirect tensile strength after moisture damage, while it increases the indirect tensile strength at dry condition by 7 %. On the other hand, significant influence of carbon fibers on moisture susceptibility of porous asphalt concrete could be observed. Implementation of carbon fibers has increased the tensile strength ratio TSR of porous asphalt concrete by 39 %.

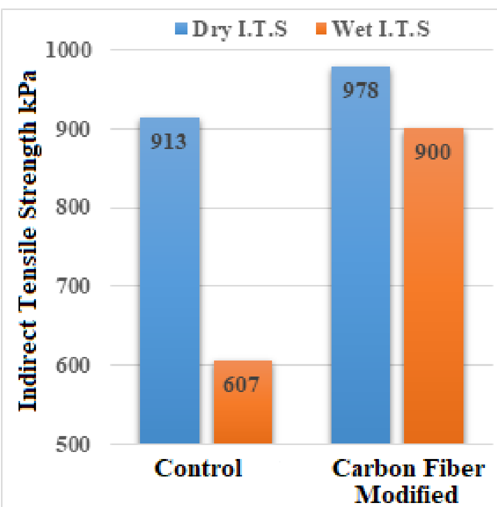

Figure 8. Influence of carbon fibers on ITS

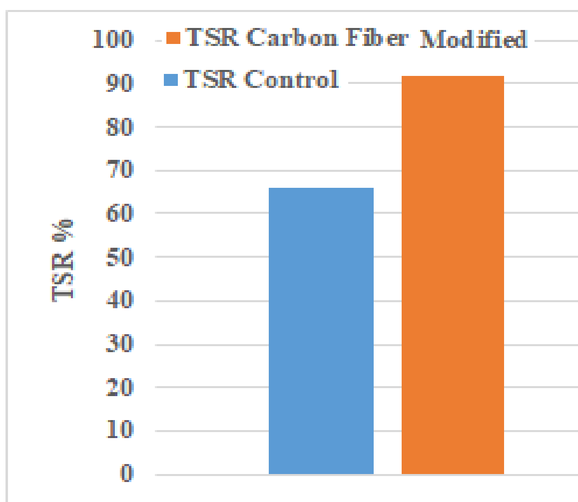

Figure 9. Impact of carbon fibers on TSR

Influence of Carbon Fibers on Abrasion loss and Drain-Down of Porous Asphalt Concrete

Porous asphalt concrete specimens of Marshall size have been prepared with 0.3 % of carbon fibers by weight of the mix. Control specimens without carbon fibers were also prepared. Specimens were subjected to cantabro abrasion loss determination. Figure10 demonstrates the influence of carbon fibers on the abrasion loss. A significant influence of carbon fibers on the abrasion loss could be detected. The abrasion loss was decreased by 48% after implementation of the carbon fibers in the mixture as compared to the control mixture. On the other hand, as shown in Figure 11, implementation of carbon fibers was able to reduce the drain down by 72 % as the fibers act as a barrier to the eroded materials, thus the mixture maintains its properties and gradients, which leads to support the durability. Such findings agree with (Hardiman, 2005).

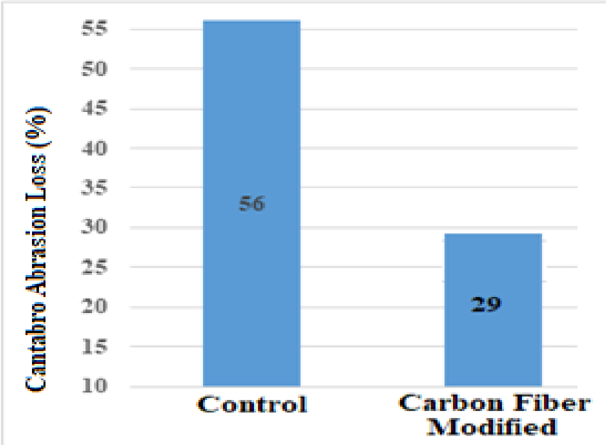

Figure10. Impact of carbon fibers on abrasion loss

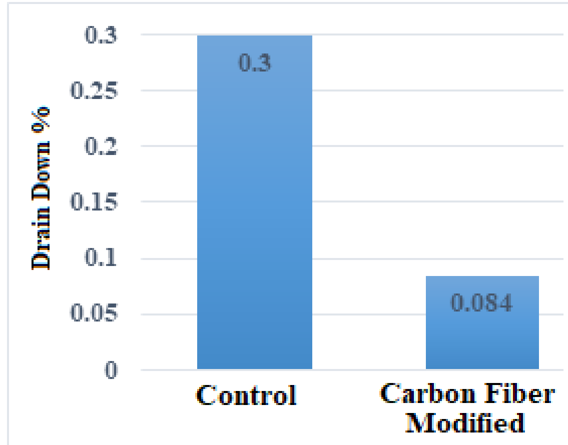

Figure 11. Impact of carbon fibers on drain down

Influence of Carbon Fibers on Permeability of Porous Asphalt Permeability

As demonstrated in Figure 12, the mixes with carbon fibers exhibited relatively lower K values as compared to that of control mixture. This may be attributed to the fact that as the fibers operate on a wall that surrounds voids and reduces their effectiveness in filtration. ASTM recommends that the coefficient of permeability of 100 m/day is a minimum acceptable for porous pavement. The permeability declines by 59.5 % after implementation of carbon fibers as compared to the control mixture. However, it is noted that when using the water suction pump, the permeability increased by(300 and 519) % for control and modified mixture as compared to the case before the water suction pump. The pump can be used for drainage purposes in places of large yards within residential complexes, schools, or religion shrines. Similar findings were reported by (Hardiman, 2005).

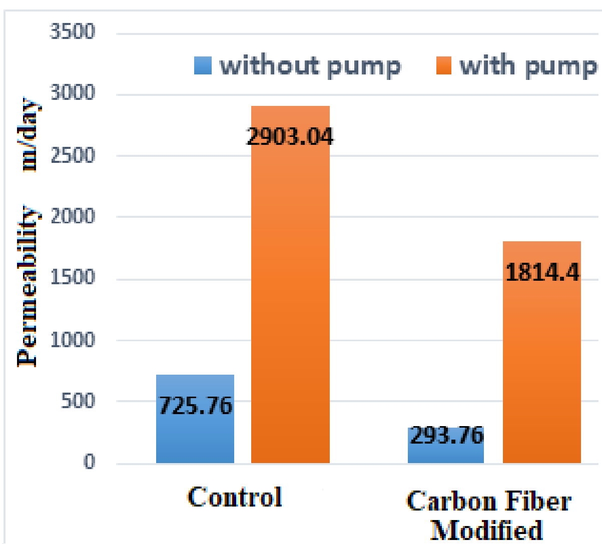

Figure 12. Influence of carbon fibers on Permeability

5. CONCLUSION

Based on the limitation of materials and testing methods adopted, the following conclusions may be drawn.

1. Carbon fibers were able to almost reserve the indirect tensile strength after moisture damage, while it increases the indirect tensile strength at dry condition by 7 %.
2. Implementation of carbon fibers have increased the tensile strength ratio TSR of porous asphalt concrete by 39 %.
3. The abrasion loss was decreased by 48% after implementation of the carbon fibers in the mixture when compared to the control mixture. Implementation of carbon fibers was able to reduce the drain down by 72 %.
4. The permeability declines by 59.5 % after implementation of carbon fibers as compared to the control mixture. However, the permeability increased by (300 and 519) % for control and modified mixture as compared to the case before the water suction pump.

5.It is recommended to use the water suction pump for drainage purposes in places of large yards within residential complexes, schools, or religion shrines.

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