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Assessing the deformation of permeable asphalt concrete

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Abstract

Permeable asphalt concrete pavement is the pavement that allows water to infiltrate through its surface. This could support the skid resistance at heavy rainfall areas and assess in fast drainage of the rainfall. In this investigation, the resistance to permanent deformation under repeated compressive stresses of permeable asphalt pavement was assessed. The influence of incorporating carbon fibers into the porous asphalt concrete surface layer was also monitored. Permeable Asphalt concrete specimens of 101.6 mm length and 101.6 mm of diameter have been prepared in the laboratory at optimum binder content of 5.2 %. Another set of specimens were prepared at optimum binder and 0.3 % carbon fiber percentages for comparison. Specimens were subjected to three levels of repeated compressive stresses of (0.068, 0.138 and 0.206) MPa in the Pneumatic Repeated Load System PRLS at 20°C. It was noted that the addition of carbon fibers has improved the resistance to permanent deformation of permeable asphalt concrete after practicing 1200 load repetitions by (17, 17.8 and 10) % under the stress level of (0.068, 0.138 and 0.206) MPa respectively. On the other hand, the deformation after the first load repetition (intercept) decline by (10.2, 30.2, and 40) % under the stress level of (0.068, 0.138 and 0.206) MPa respectively when carbon fibers were incorporated in the mixture as compared to the control specimens.

Keywords: permeable pavement, asphalt concrete, carbon fibers, deformation, repeated compressive stress

1. Introduction

Implication of permeable asphalt concrete pavement in heavy rainfall areas is considered as a sustainable issue from the safety and environment protection points of view, Sarsam and Majeed, 2020 [1]. The application of permeable pavement is indicated in parking areas and in sections of horizontal curves geometry at heavy rainfall areas as mentioned by Ping and Fang, 2005 [2] and Elvik and Greibe, 2005 [3]. The mixture of such pavement surface layer can have a void index ranging between 16% and 22%, to allow proper drainage, WAPA, 2015 [4]. Hanim *et al*., 2009 [5] stated that the water ponding on the road surface is caused by the heavy precipitation of high intensity rain fall. The water ponding problem during the rainy condition can be decreased by the employment of the permeable asphalt (porous asphalt) as a surfacing road pavement. The design of pavement systems has not emphasized drainage as reported by Blanco *et al*, 2003 [6]. It was stated that a major part of the damage found in pavement systems is caused by poor subsurface drainage, often the result of base materials that are not providing adequate drainage. Putman and Kline, 2012 [7] stated that permeable 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. Kanitpong *et al*., 2003 [8] 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. As reported by Fini *et al*., 2017 [9], 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. Miradi *et al*, 2009 [10] reported that the behavior of asphalt concrete under load as degeneration of the material and the limit of elasticity can be described by the stress-strain relationship for asphalt concrete in compression. Prachantrikal, 2002 [11] stated that the presence of water, lack of drainage, and the cyclic loading applied due to vehicles on the pavement result in high pore-water pressures, which in turn cause a significant loss in effective strength in the base and eventually pavement failure. Qin, 2019 [12] 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. Patil *et al*., 2018 [13] Investigated the performance of aggregates and porous asphalt used in projects, such as properties of aggregates like impact value, crushing value, specific gravity, abrasion test. Tests performance on porous asphalt includes ductility test, stripping value test and penetration test. The impact of such properties on reduction of splash and spray from Travelling vehicle, and roadway noise was investigated. Chairuddin *et al*., 2016 [14] focuses to examine the compressive strength and the stress strain relationship of permeable asphalt. It was found that the stress strain curve of compression test results for asphalt concrete was same with stress strain curve of the porous asphalt while the compressive strength was 2.4 MPa and the voids ratio was 19.2 %. Ma *et al*., 2018 [15] evaluated the approaches of implementing additives to improve the durability and strength of the porous asphalt through laboratory testing. It was found that fiber enhanced its durability and anti-cracking performance at low temperature; hydrated lime improved its moisture stability while weakening its durability. It is concluded that polyester fiber should be used in all porous asphalt. Norhidayah *et al*., 2019 [16] 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. The influence of the microstructures of pores on anti-clogging performance of porous asphalt concrete was investigated by Hu *et al*., 2020 [17]. It was concluded that the regular shape presents excellent anti-clogging performance. The specimen thickness was not found to be a significant factor affecting hydraulic conductivity of laboratory prepared specimens. Shukla *et al*., 2014 [18] concluded that fiber modified Asphalt mixtures have shown increased stiffness and resistance to permanent deformation. Fatigue characteristics of the mixtures were also improved. Kumar *et al*. 2009 [19] has reported that the permanent deformation decreases with an increase in fibers content, indicating a decrease in rutting potential. Mahrez *et al*. 2005 [20] found that the addition of fiber has the potential to resist structural distress that occur in road pavement as result of increased traffic loading, thus improving fatigue life by increasing the resistance to cracking and permanent deformation.

The aim of the present investigation is to assess the permanent deformation under repeated compressive stresses. The influence of incorporating carbon fibers into the permeable asphalt concrete surface layer on the resistance to rutting will be assessed.

2. Materials and methods

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

2.1. Asphalt Cement

Asphalt cement of penetration grade 40-50 was implemented in this investigation as a binder. It was obtained from Dourah refinery. The important physical properties for the 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 [21] specification.

Table 1: Physical Properties of Asphalt Cement

Test procedure as per ASTM, 2013 [22]	SCRB, 2003 [21] Limitations	Unit	Result
Penetration (25°C, 100g, 5sec) ASTM D 5	40-50	1/10mm	41
Ductility (25°C, 5cm/min). ASTM D 113	≥ 100	Cm	162
Softening point (ring & ball). ASTM D 36	50-60	°C	51
After Thin-Film Oven Test ASTM D-1754			
Retained penetration of original, % ASTM D 5	> 55	1/10mm	61
Ductility at 25 °C, 5cm/min, (cm) ASTM D-113	> 25	Cm	89
Loss in weight (163°C, 50g,5h) % ASTM D-1754	-	%	0.175

2.2 Coarse Aggregates

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 19mm to 4.75mm as well-defined in SCRB, 2003 [21] requirement. The physical properties of the coarse aggregates are listed in Table 2.

Table 2: Physical Properties of Al-Nibaee Coarse and fine Aggregates

Property	Coarse Aggregate
Bulk Specific Gravity (ASTM C 127 and C 128)	2.610
Apparent Specific Gravity (ASTM C 127 and C 128)	2.641
Percent Water Absorption (ASTM C 127 and C 128)	0.570
Percent Wear (Los-Angeles Abrasion) (ASTM C 131)	13.08

2.3 Fine Aggregates

Crushed Fine aggregates 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 gradation ranges from the size of 4.75 mm to 0.075 mm. The physical properties of fine aggregates are presented in Table 3.

Table 3: Physical Properties of Fine Aggregate

Property	ASTM, 2015 [22] Designation No.	Fine Aggregate	SCRB R/9, 2003 [21] Specification
Bulk Specific Gravity	C-128	2.604	-------
Apparent Specific Gravity	C-128	2.664	-------
Percent Water Absorption %	C-128	1.419	-------

2.4 Mineral Filler

Limestone dust is used in this work as mineral filler. Its source is a lime plant at 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

2.5 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 Fig. 1. 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

Fig 1: Carbon fibers Implemented

2.6 Selection of Asphalt Concrete Combined Gradation

According to ASTM D-7064, 2015 [22] specification, the nominal maximum size of aggregate is 12.5 mm for wearing course. Many trial aggregate gradations were selected and tried. The final adopted gradation is demonstrated in Fig. 2.

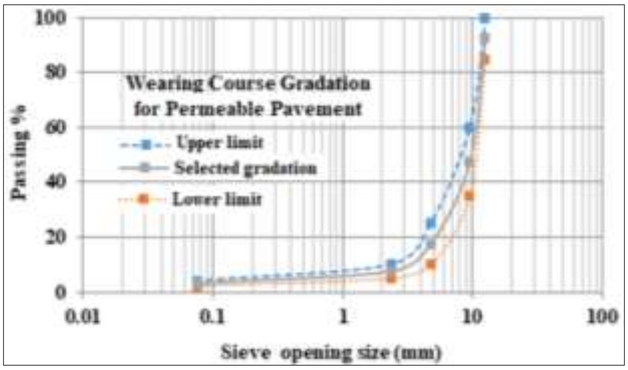

Fig 2: Selected gradation for wearing course

3. Testing Methods

3.1 Preparation of Permeable 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 film 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 added as 0.3% of the total asphalt concrete mixture weight. The fibers were added to the aggregate before heating and mixed thoroughly. Details of mixture design can be found in Sarsam and Majeed, 2020 [1].

3.2 Preparation of Permeable Asphalt Concrete Specimens

Specimens of 101.6 mm in height and 101.6 mm in diameter were prepared. Mold and spatula 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 a static compaction to the target bulk density of 2.018 gm/cm^3. The specimens were left overnight in mold to cool at room temperature and then it was extracted from the mold with the aid of mechanical jack. Fig. 3 exhibit part of the prepared specimens.

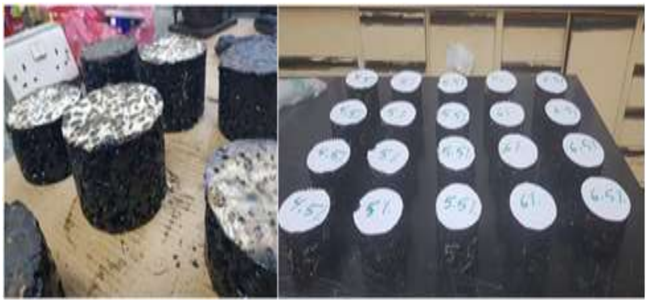

Fig 3: Part of the prepared specimens

3.3 Testing of Asphalt Concrete Specimens Under Repeated Compressive Stresses

Asphalt concrete specimens of 101.6 mm diameter and 101.6 mm height were prepared. A set of six specimens were prepared for each mixture. The specimens were conditioned at room temperature of 20 ºC for two hours. Specimens were subjected to the repeated compressive stress using the PRLS apparatus. Repetitive compressive stress loading was applied on the specimen in the form of rectangular wave while the vertical strain was monitored under the load repetitions. The load repetitions were applied under constant stress level of 0.138 MPa. A loading frequency of 60 cycles per minute was applied while the loading sequence for each cycle is 0.1 second of load duration and 0.9 second of rest period. The testing temperatures of (20) ºC was maintained throughout the test. Permanent deformation and resilient modulus of these specimens was determined at temperature of 20^{0}C with different stress levels of (0.069, 0.138, and 0.207) MPa. The test was continued for 1200 load repetitions, upon completion of test, the recording was terminated. Test was conducted as per ASTM, 2015 [22]. Fig. 4 exhibit the repeated compressive stress setup.

Fig 4: Repeated compressive stress in the PRLS

4. Results and Discussion

4.1 Permanent Deformation Behavior under Repeated Compressive Stress at Different Levels of stress

Permanent deformation is one of the common forms of pavement distress and is mainly generated by accumulation of deformation under repetitive compressive stress due to traffic loading. The effect of adding carbon fibers on the resistance to permanent deformation in permeable asphalt pavement was evaluated. Control specimens and other specimens with carbon fibers were exposed to repeated compressive stresses using the PRLS device under the implemented stress levels of (0.0689, 0.1379, and 0.2068) MPa (at 20 ° C). The permanent deformation of the mixtures was monitored and calculated throughout the loading process. Table 6 exhibit the values of permanent deformation of the two mixtures. Fig. 5 exhibit the variation in permanent deformation with various stress levels before and after implication of carbon fibers.

Table 6: Permanent Microstrain under Repeated Compressive Strength at Different Levels of Stress.

Mixture Type	Permanent Deformation (Microstrain) Compressive Stress level		
	0.068 MPa	0.138 MPa	0.206 MPa
Control at OAC	5900	15700	17900
OAC with C.F.	4900	12900	16100

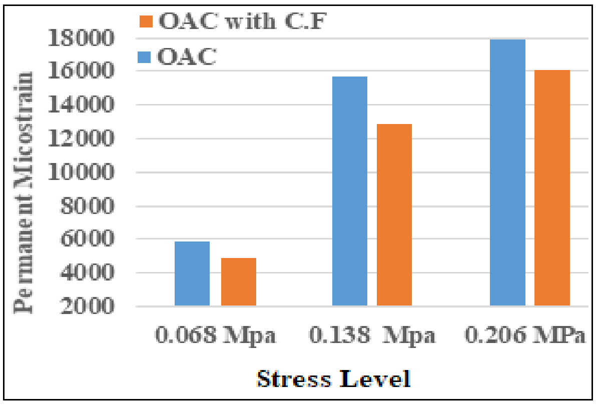

Fig 5: Variation of Permanent Microstrain under Repeated Compressive Strength

Based on the results, carbon fibers exhibit an influence on plastics response of asphalt materials. The difference in permanent deformation was related to the type of asphalt mixture as shown in Table 6 and Fig. 5. It can be observed that the value of permanent deformation decreased by (16.9,17.8, and10.1) % when using carbon fibers under Stress level of (0.068, 0.138, 0.206) MPa, respectively. It can be noted that the development of permanent deformation is highly dependent on the level of stress, and the permanent deformation increases with the increase of compressive stress. When adding carbon fibers to the mixture, a reduction in permanent deformation can be observed. This may be attributed to the fact that more voids are clogged with fibers, which increases the mixture's stiffness and provides greater resistance to deformation as shown in Fig. 5. Table 7 demonstrates the influence of carbon fibers on permanent deformation parameters. The intercept represents the permanent deformation (microstrain) after the first load repetition, while the slope is the rate of deformation throughout the repeated loading period. A significant reduction in the permanent deformation could be detected after implementation of carbon fibers. The initial deformation decreases by (10, 30 and 40) % under Stress level of (0.068, 0.138, 0.206) MPa when carbon fibers were implemented. On the other hand, the slope become steeper in general as the stress level increase regardless of the specimen type. Similar findings were reported by Chairuddin *et al*., 2016 [14].

Table 7: Permanent Deformation Parameters

Permanent Deformation Parameters						
Stress level	0.068 MPa		0.138 MPa		0.206 MPa	
Mix. Type	Intercept Microstrain	Slope	Intercept Microstrain	Slope	Intercept Microstrain	Slope
Control at OAC	517.7	0.3098	1209	0.3146	2014	0.2913
With C.F	464.7	0.3028	844	0.3588	1210	0.3517

Fig. 6 demonstrates the permanent deformation and loading cycles relationship for control mixture while Fig. 7 demonstrates the permanent deformation and loading cycles relationship for carbon fibers treated mixture. It can be noted that implementation of carbon fibers exhibits a positive influence on the permeable asphalt concrete as the initial and final permanent deformation decreases. Similar findings were reported by Hamzah and Yatim, 2007 [23].

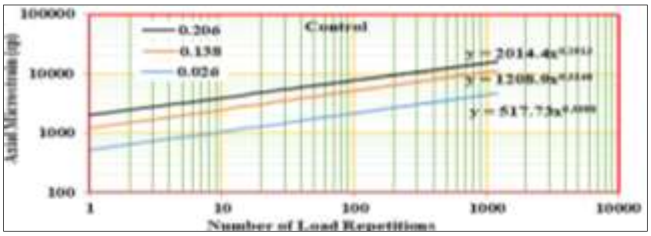

Fig 6: Relationship Between Permanent Deformation & Loading Cycles for Control Mixture

Fig. 7. Relationship Between Permanent Deformation & Loading Cycles for Carbon Fibers Mixture Fig. 8 shows the rutting resistance behavior of permeable asphalt concrete under various levels of compressive stress. It can be observed that the resistance to permanent deformation (rutting) of the specimens after practicing 1200 load repetitions increases by (17, 17.8 and 10) % under Stress level of (0.068, 0.138, 0.206) MPa when carbon fibers were implemented. Such finding agrees with the work reported by Shukla *et al*., 2014 [18].

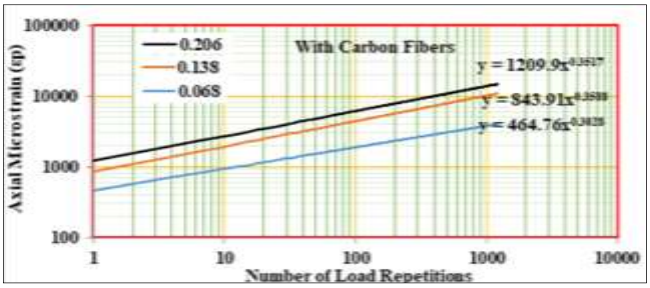

Fig 8: Rutting Resistance of Permeable Pavement

4.2 Resilient Modulus Behaviour under Repeated Compressive Stress

The resilient modulus (MR) is a characteristic of the base materials. It represents the ratio of applied stress to recoverable strain that occurs after the removal of the applied stress. MR was determined from the repeated compressive stresses on the specimen in the PRLS chamber at 20° C. Table 8 exhibit the obtained MR at various stress levels.

Table 8: Resilient Modulus (MPa) under Repeated Compressive Stress

	Resilient Modulus (MPa)		
	Compressive Stress Level		
Mix. Type	0.068 MPa	0.138 MPa	0.206 MPa
OAC (Control)	7100	5600	4180
OAC with C.F	8150	6400	5000

The MR test results of the permeable asphalt mixture declines as the stress level increases regardless of the specimen type. The value of the resilient modulus MR decreased by (21 and 41) % for control mixture at (0.138 and 0.206) MPa respectively. While the MR test results for carbon treated mixture decline by (21.4 and 38.6) % at (0.138 and at 0.206) MPa respectively as compared to the 0.068 MPa stress level. On the other hand, the MR of the carbon fiber treated mixture increased by (14.7, 14.2 and 19.6) % under (0.068, 0.138 and 0.206) MPa of stress levels respectively as compared to the control mixture. This can be attributed to the fact that adding carbon fibers as an enhancer for the permanence of the porous mixture will increase the viscosity of the binder or more precisely reduce or eliminate some voids, which in turn increases the flexibility of the mixture. Such finding agrees with the work reported by Mahrez *et al*. 2005 [20].

5. Conclusion

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

1. Permanent deformation decreases by (16. 9, 17. 8, and10.1) % when using carbon fibers as an additive under Stress level of (0.068, 0.138, 0.206) MPa, respectively.
2. The initial deformation (intercept) decreases by (10, 30 and 40) % under Stress level of (0.068, 0.138, 0.206) MPa when carbon fibers were implemented, while the slope become steeper in general as the stress level increase regardless of the specimen type.
3. The resilient modulus MR of the carbon fiber treated mixture increased by (14.7, 14.2 and 19.6) % under (0.068, 0.138 and 0.206) MPa of stress levels respectively as compared to the control mixture.
4. The resistance to permanent deformation (rutting) of the specimens after practicing 1200 load repetitions increases by (17, 17.8 and 10) % under Stress level of (0.068, 0.138, 0.206) MPa when carbon fibers were implemented.

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