

Producing Porous Asphalt in Palestine According to ASTM D7064

Shafik Jendia¹, Mousa Krezem²

¹ Professor of Highway Engineering, Islamic University of Gaza, Palestine

² Msc. Degree of Infrastructure Engineering, Islamic University of Gaza, Palestine

Abstract: Porous Asphalt (PA) pavements offer an alternative technology for storm water management because it differs from traditional asphalt pavement designs in its high air void ratio which can reach more than 20 %. Aim of the research is to produce porous asphalt according to ASTM D7064 and to study the different characteristics and properties of porous asphalt. The practical program of this study starts with studying the different properties of the used aggregates in preparing porous asphalt samples, then studying the different characteristics of used bitumen (density, ductility .. etc.). After that porous asphalt mix was prepared and PA samples was subjected to required laboratory tests to determine the air void ratios ($V_a\%$), optimum bitumen content (OBC) and permeability coefficient. The test results found that $V_a\%$ ranges between 21 % to 29 % by several bitumen contents. The optimum bitumen content OBC of the non-modified porous asphalt was 3.5 % and the permeability coefficient reached approximately 55 m/day.

Keywords- Porous Asphalt, air void ratio, Optimum Bitumen Content Draindown Test, Cantabro Abrasion Test, Marshal Test, ASTM D7064.

Introduction

Porous Asphalt (PA) materials are an open-graded mixes composed of relatively uniform graded aggregate and bitumen or modified binders. PA is mainly used as drainage layer, either at the pavement surface called Permeable Friction Courses (PFC) or within the pavement structure [1].

A layer of porous asphalt with thickness varies in the range of 20-100 mm and an air void ratio that is generally between 18 – 22 % is normally placed as an overlay on top of an existing conventional concrete or asphalt surface. This overlay typically is referred to as Porous Asphalt (PA), Permeable Friction Courses (PFC), or

Open Graded Friction Courses (OGFC) [2]. The high air void ratio of PA compared with dense asphalt concrete makes it as a storm water best management practice where the water goes through it rapidly- without any ponding at the surface faster than other traditional

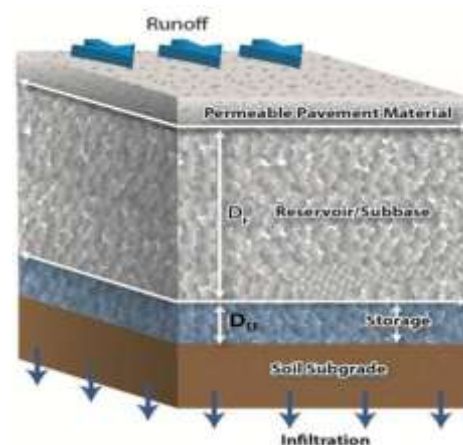


Figure (1): Cross section of Porous Asphalt pavement [4]

dense-graded pavement as shown in Figure (1) [3].

PA is used all over the world mainly for two pavement applications; the first one as wearing courses on high-speed roadways where a thin layer of porous asphalt ranging from 20 to 50 mm thick is placed over a conventional impermeable pavement surface, this overlay allows water to drain into the porous layer and then moves laterally within it which highly helps in improving roadway safety. The second application where PA can also be used is for storm water management purposes where the quantity of storm water runoff is significantly reduced due to infiltration through the porous asphalt layer. In the second type of applications, a thicker porous asphalt layer (50–100 mm thick) is placed over an open graded aggregate base course that acts as a reservoir for storm water before it infiltrates into the underlying soil [5]. PA was produced previously in the laboratory based on the German specifications as a new technology in Palestine through a published scientific paper in this topic titled as: “Porous Asphalt: A New Pavement Technology in Palestine” [6].

Objectives of the study

The main aim of this paper is to study the purpose, properties, advantages, disadvantages, of the porous asphalt and finally determine the possibility of producing it in Palestine. More precisely, this paper represents a trial to:

1. Determine the most suitable aggregate gradation which should be used in PA mix according to ASTM specifications.

2. Obtain the optimum design of PA by determination $V_a\%$, OBC, stability and flow.
3. Evaluate the permeability of PA.

Advantages of Porous Asphalt

Although its useful properties and benefits, PA has not been paved in Palestine yet. Some of these advantages are presented below [7, 8]:

1. Reduction in Splash and Spray, Reduced Aquaplaning
2. Reduction in Light Reflection and Headlight Glare
3. Noise Reduction on the street surface
4. Improvement in Skid Resistance
5. Rut-Resistance
6. Requires less need for curbing and storm sewers
7. Recharging groundwater supply

Disadvantages of Porous Asphalt

Despite its useful properties and advantages, a high level of care still be needed before the use of PA due to its following disadvantages [5, 7, 8, 9, 10, 11]:

1. Stripping:
Big amounts of water that penetrate porous asphalt due to its high permeability can make the asphalt in wet condition for long periods where some of these water amounts are not properly drained and remains in the asphalt's structure. This continuous wet condition of asphalt increases the rate of bitumen's stripping from the aggregate surfaces [5].
2. Raveling:
Raveling is defined as a pavement distress resulting from the loss of individual aggregate particles at the surface of the pavement due to a loss of adhesion between the binder and the aggregate. In

porous asphalt, and due to the high air voids content, oxygen, sunlight and water have access to a higher surface area of mixture which increasing the possibility of bitumen exposure to air compared to impervious asphalt mixes. This exposure to the air can lead to premature oxidation of the binder, thus making it brittle and leading to raveling [7].

3. Aging:

One of the main properties in porous asphalt mixes is its high porosity which creates a suitable environment to the binder film in the mix to be exposed to oxygen, sunlight, water etc. This continuously exposure results in bitumen hardening and thus aggregated can be stripped easily from the asphalt mixes which leads finally to shorter service life of porous asphalt than conventional dense mixes [8].

4. Draindown:

Draindown occurs in porous asphalt as a result of lack of fine aggregate which is done to reach higher permeability rates than dense asphalt mixes. Also the excess asphalt binder (bitumen) which is used to increase durability can cause draindown. This draindown appears as an excess asphalt binder that drains out of a porous asphalt mixture. Moreover, the high temperatures in summer can be a main reason for draindown which soften the binder and by gravity it gradually downwards in the asphalt layers until reaching stability in a cooler portion of the pavement. This phenomenon causes big problems in porous asphalt where the excess bitumen which downwards in the asphalt structure can clog these layers and thus decreases the permeability rates of the porous asphalt [7]. To prevent draindown in porous asphalt, then

stabilizing additives should be used such as polymers which stiffen the asphalt binder and fibers which absorb the additional binder content [9].

5. Winter Maintenance:

Lower thermal conductivity of the porous asphalt leads to make it colder than the dense asphalt mixes and thus this can facilitate the early settlement of snow and remains longer on the asphalt surface[10].

Some other issues need high degree of care when dealing with porous asphalt like:

6. Reduction in Porosity [11]

7. Shorter Service Life

Materials and Testing Program

A. Stage One: Determination of Aggregate and Bitumen Properties

A.1 Aggregate Properties

Four main types of aggregates were used in this experimental study. Table (1) highlights the different types of aggregate properties.

Table (1): Aggregate test results according to ASTM specifications

Specification	Test Results	Reference
Specific Gravity (g/cm^3)	2.64–2.79	ASTM C127-15 C128-15
Water Absorption (%)	0.6-0.8	ASTM C128
Abrasion Loss Value (%)	13.1-16.2	ASTM C128
Sieve Analysis of Aggregates and Blending Results	See Appendix (A)	

A.2 Bitumen Properties

Bitumen is tested in order to determine its mechanical properties. Table (2) illustrates the bitumen characteristics.

Table (2): Bitumen test results according to ASTM specifications

Test	Results	Reference
Density	1.03 (g/ml)	ASTM D 3289-08
Penetration	59 (1/10 mm)	ASTM D5/D5M-13
Flash Point	289 (° C)	ASTM D92 – 12b
Ductility	> 150 (cm)	ASTM D113-07
Solubility	99.5 (%)	ASTM D2042-09
Softening Point	49 (° C)	ASTM D 36

B. Stage Two: Blending Process

According to ASTM D7064 specifications, three different aggregate gradation curves were selected using blending process. Blending process (Appendix (A)) is based on a trail mathematical approach through proposing trial percentages for each aggregate type and finally comparing the passing percentages for each sieve with its equivalent in the specification limits. If the resulted gradation is within the acceptable limits, then the process is finalized with no further adjustments need to be made and this gradation is considered to be the chosen one; if not, an adjustment in aggregate sizes proportions should be made and the calculations repeated until reaching a gradation in which all aggregate sizes are within the acceptable limits [12]. The previous procedure was used 3 times to select 3 gradations within the ASTM D7064 limits. One of the 3 gradation curves is shown in Figure (2) and the

calculation of all gradations is illustrated in Appendix [A].

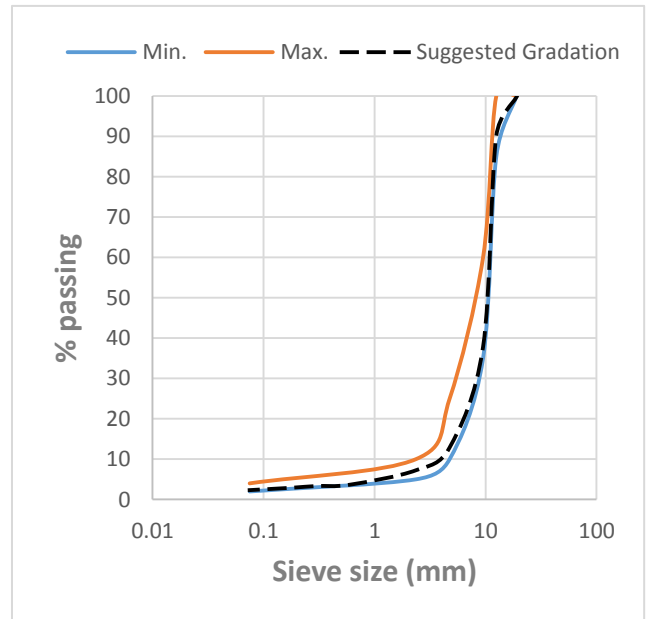


Figure (2): Suggested gradation curve in comparison with ASTM

C. Stage Three: Determination of PA properties

C.1 Selection of the Most Suitable Gradation Curve

This stage aims to select the most suitable gradation from the three proposed ones in stage 2 based on the maximum air void ratio. To determine the air void ratio (V_a %) in porous asphalt, 12 porous asphalt samples (4 samples for each of 3 gradations) were produced with a trail asphalt content 6% as stated in ASTM D7064 Specifications [13]. After that, Bulk Bulk Specific Gravity (G_{mb}) and Maximum Theoretical Specific Gravity (G_{mm}) were calculated to use them in finding the percent air void ratio (V_a %) for each asphalt mix using Equation (1)

$$V_a \% = 100 \left(1 - \frac{G_{mb}}{G_{mm}} \right) \dots \text{Equation (1)}$$

Results of air void ratios are shown in Table (3):

Table (3): G_{mb}, G_{mm} & V_a % for 3 different aggregate gradations

Item	Gradation I	Gradation II	Gradation III
G _{mb}	1.946	1.866	1.857
G _{mm}	2.427	2.428	2.424
V _a %	19.82	23.13	24.36

Based on the previous results in Table (3), it is clearly shown that Gradation III (in Appendix [A]) is the most suitable one where it gives the highest air void ratio (24.36 %) with the stated percentages of four different aggregate types in Table (4)

Table (4): Different aggregate percentages of the most suitable gradation for porous asphalt

Aggregate Type	Percentage %
Filler (0/0.075 mm)	3%
Simsimia (0/0/12 mm)	17%
Adasia (0//19 mm)	75%
Folia (0/25 mm)	5%
Total	100%

C.2 Conducting Draindown and Cantabro Abrasion Tests

In order to determine the OBC, 39 PA samples were prepared using 6 different bitumen contents (3.5-6 % with 0.5% increment) and subjected for laboratory tests as shown in Tables (5) and (6):

Table (5): Number and purpose of the produced PA samples in the test program

No. of Produced PA Samples	Purpose
6	For Air Void Ratio Calculations

No. of Produced PA Samples	Purpose
6	For Draindown Test (ASTM D6390)
18	For Cantabro Abrasion Tests (ASTM C131)
9	For Marshal Test (Stability and Flow)

Table (6): Tests results of mechanical properties of PA using 6 different bitumen contents

Bitumen Value (%)	V _a (%)	Draindown (%)	Abrasion Loss (%)
3.5	28.9	0.04	61
4	25	0.07	59.6
4.5	21.6	0.09	57.1
5	27.3	0.12	55.4
5.5	28	0.16	51.3
6	24.4	0.21	47.8

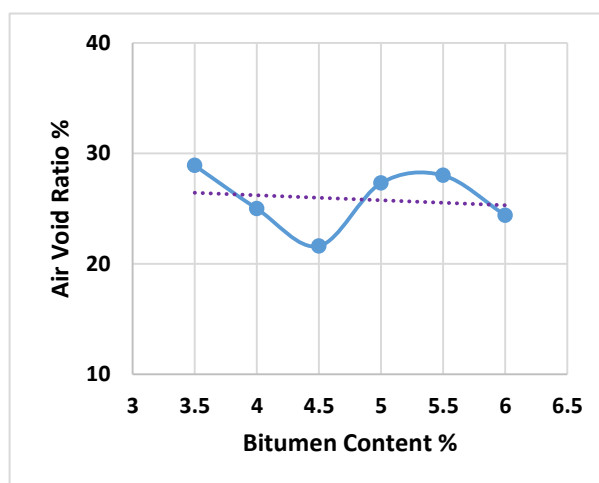


Figure (3): Air void ratio (V_a %) vs. bitumen content (%)

As stated in ASTM D7064, the selected Open Graded Friction Course (OGFC) should be the one which meets the below specifications [13]:

- Total air void ratio should be minimum 18%

- Draindown value should not exceed 0.3%
- Abrasion Loss on un-aged Specimens from the Cantabro test should not exceed 20% where the Cantabro abrasion criteria are optional to be used in judgment as per ASTM D7064 recommendations.

Table (6) and Figure (3) indicate that when bitumen content increases, the air void ratio decreases until reaching high amounts of bitumen more than 4.5 % then the air void ratio increases. This can be referred to the low content of filler in relative to the increased bitumen content (especially at the high contents 5, 5.5 & 6%) in PA mixes. The high bitumen content lead finally to decrease the Bulk Specific Gravity (G_{mb}) and thus increasing the calculated air void ratio in the PA sample (Eq. 1). Accordingly, it is appeared that the unmodified PA mix cannot be used with high bitumen contents more than 4.5 % percentages so that from the previous results, it is clearly shown that 3.5%, 4% and 4.5% bitumen contents are the most three contents that met ASTM D7064 specifications in terms of air void ratios and draindown values. Therefore, these 3 bitumen contents were used to produce new 9 porous asphalt samples to be tested against their stability and flow (Marshall Test) as presented in the next step.

C.3 Conducting Marshall Test to determine Optimum Bitumen Content (OBC)

9 PA samples were prepared using the most suitable bitumen contents (3.5 %, 4 % and 4.5 %) (3 samples for each bitumen content) to determine their stability and flow using Marshall test. The results of this test resulted in finding the

OBC which gave the highest stability values. Results are given in Table (7).

Table (7): Stability and flow values for PA according to used bitumen content

Bitumen Content (%)	Stability (KN)	Flow (mm)
3.5	4.95	3.6
4	3.46	3.8
4.5	4.44	4

It is clearly appeared that bitumen content **3.5%** is the content which gives the highest stability of the asphalt mix (504.55 Kg \approx 4.95 KN), accordingly **3.5 %** is taken as the **OBC**.

D. Stage Four: Determination of Permeability Coefficient (K) of Porous Asphalt Mix

To evaluate the permeability of PA, the falling head test was used. The testing process included preparing 2 PA samples from 2 different bitumen contents; 3.5 % “OBC” and 4 % “for comparison purposes”. Table (8) highlights the final results of permeability coefficient for each bitumen content where the results indicate that using bitumen content 3.5% results in higher permeability of PA. More details of calculating the permeability coefficient are presented in Appendix [B].

Table (8): Permeability coefficient (k) for porous asphalt using 2 different bitumen Contents

Bitumen Content	Permeability Coefficient (K) (meter/day)
3.5%	55.00
4%	52.56

Conclusions

Based on experimental work results for porous asphalt mixtures, the following conclusions can be drawn:

- a. Porous asphalt can be easily produced in Palestine using the local available materials according to ASTM specifications (ASTM D7064).
- b. Porous asphalt has a high ratio of air void ratio that can reach more than 25% compared with air void ratio in dense asphalt concrete which lies between (3-7) %.
- c. Using different bitumen contents is leading to different air void ratios where the air void ratios were in the range (21–29) % when using bitumen contents between (3.5-6) %.
- d. The optimum bitumen content of porous asphalt is 3.5 % where it is lower than the bitumen content in dense asphalt concrete which can reach more than 5% due to its higher durability compared with porous asphalt types.
- e. The optimum bitumen content is 3.5 % where it gives the highest air void ratio and lowest percentages of draindown in addition to normal value of asphalt stability.
- f. The bitumen content in porous asphalt is inversely proportional with abrasion loss values where using higher bitumen contents leads to lower abrasion loss values.
- g. Due to higher air void ratio of porous asphalt compared to dense asphalt concrete, its stability values are lower than other conventional asphalts.

Recommendations

- a. It is recommended to start using porous asphalt in Palestine in order to gain its useful properties especially those which are related to decreasing runoff water amounts due to its higher permeability.
- b. It is recommended to use high permeable base course and sub-base layers in porous asphalt to increase the efficiency in water infiltration especially with the high permeability of porous asphalt layer that reaches 55 m/day.
- c. It is recommended to conduct more research in porous asphalt topics to improve its durability and water infiltration characteristics especially in terms of the internal road layers (base course and sub-base).
- d. It is recommended to conduct a specific studies related to the financial costs of porous asphalt and compare it with the costs of conventional types of asphalt.
- e. It is recommended to start preparing unique Palestinian Specifications related to porous asphalt and its properties.
- f. It is required to use some modifiers in porous asphalt mixtures to enhance its stability and abrasion loss values more than those that were obtained in this study.

References

- [1] Federal Aviation Administration (FAA). (2001). "Hot Mix Asphalt Paving Handbook." Advisory Circular No. 150/5370-14A, U.S. Department of Transportation, Washington, D.C.
- [2] Barrett, M. E., and Shaw, C. B. (2006). "Stormwater Quality Benefits of a Porous Asphalt Overlay (No. FHWA/TX-07/0-4605-2)". Center for Transportation Research, University of Texas at Austin.
- [3] Putman, B. J., and Kline, L. C. (2012). "Comparison of Mix Design Methods for Porous Asphalt Mixtures". *Journal of Materials in Civil Engineering*, 24(11), PP 1359-1367.
- [4] Permeable pavement, https://stormwater.pca.state.mn.us/index.php?title=File:Permeable_pavement_volume_credit_2.png, accessed on 27th November 2018.
- [5] Ali, N., Ramli, M. I., and Hustim, M. (2012). "Porous Asphalt 'S Contribution on Road Safety and Environment", 8th International Symposium on Lowland Technology September 11-13, 2012 in Bali, Indonesia.
- [6] Jendia, S., AlDahdooh, Z., AbuRahma, M., et al. (2018). "Porous Asphalt: A New Pavement Technology in Palestine". *Journal of Engineering Research and Technology*, 5(1).
- [7] Lyons, K. R., and Putman, B. J. (2013). "Laboratory Evaluation of Stabilizing Methods for Porous Asphalt Mixtures". *Construction and Building Materials*, 49, 772-780.
- [8] Hoban T W S, Liversedge F and Searby R. (1985). "Recent Developments in Pervious Macadam Surfaces" , Proc. 3rd Eurobitumen Symp., The Hague, pp 635-640.
- [9] Shankar, A. U., Suresha, S. N., and Saikumar, G. M. V. S. (2014). "Properties of Porous Friction Course Mixes For Flexible Pavements". *Indian Highways*, 42 (3).
- [10] Palatová, M. (2012). "New Trends in the Construction of Flexible Pavements", M.Sc Thesis: BRNO University of Technology.
- [11] Van Heystraeten, G., and Moraux, C. (1990). "Ten Years' Experience of Porous Asphalt in Belgium". *Transportation Research Record*, (1265).
- [12] Jendia, S. (2000). "Highway Engineering-Structural Design". Gaza: Dar El-Manara Library.
- [13] American Society of Testing and Materials (ASTM). ASTM D7064/D7064M – 08 "Standard Practice for Open-Graded Friction Course (OGFC) Mix Design".

Appendix A

Aggregates Blending

Table A.1: Suggested Percentages for Porous Asphalt Aggregate Mix

Aggregate mix	Grain size (mm)										Suggested percents for final agg. Mix
	0.075	0.18	0.3	0.6	2.36	4.75	9.5	12.5	19	25	
Filler	59.68	76.94	88.73	98.06	100.00	100.00	100.00	100.00	100.00	100.00	3.00%
	1.79	2.31	2.66	2.94	3.00	3.00	3.00	3.00	3.00	3.00	
Simsimia	1.34	1.46	1.57	1.62	22.00	54.70	95.63	100.00	100.00	100.00	17.00%
	0.23	0.25	0.27	0.28	3.74	9.30	16.26	17.00	17.00	17.00	
Adasia	0.38	0.45	0.52	0.56	0.63	0.70	23.90	91.16	100.00	100.00	75.00%
	0.29	0.34	0.39	0.42	0.47	0.53	17.93	68.37	75.00	75.00	
Folia	0.54	0.59	0.64	0.72	0.77	1.52	13.01	35.64	95.31	100.00	5.00%
	0.03	0.03	0.03	0.04	0.04	0.08	0.65	1.78	4.77	5.00	
∑% passing	2.33	2.92	3.35	3.67	7.25	12.90	37.83	90.15	99.77	100.00	100.0%
Sieve size (mm)	0.08	0.15	0.30	0.85	2.36	4.75	9.50	12.50	19.00	25.00	
Wearing 0/ 12.5 (Min)	2				5	10	35	85	100		ASTM Specifications D7064/D7064M – 08
Wearing 0/ 12.5 (Max)	4				10	25	60	100	100		

Appendix (B)

Determination of Permeability of Porous Asphalt Mix

Permeability coefficient (K) of porous asphalt samples was calculated using the falling head test method in which k can be found using equation B.1 below:

$$K = \frac{Q*L}{A*H*T} \dots\dots\dots \text{Equation (B.1) where,}$$

- Q: volume of water infiltrated through porous asphalt sample (cm³)
- L: Sample height (cm)
- A: Cross Sectional Area of asphalt sample (cm²)
- H: height of water column (Pressure Head) (cm)
- T: Elapsed time to infiltrate water through the asphalt sample (sec.)

During the laboratory program execution, 2 porous asphalt samples with 2 different bitumen content (3.5% and 4%) were prepared for permeability test purposes. Table (B.1) below presents the results of the test.

Item		Sample 1 (3.5% Bitumen)	Sample 2 (4% Bitumen)
Q (cm ³)	Trail 1	1,893	1,877
	Trail 2	1,946	1,861
	Trail 3	1,930	1,850
Q (cm ³) (average)		1,923	1,862.67
L (cm)		7.8	7.85
D (cm)		10	10.1
A (cm ²) = $\left(\frac{\pi}{4}\right) * D^2$		78.54	80.12
H (cm)		50	50
T (sec.)		60	60

From the previous data in Table (B.1), equation (B.1) can be used to find K as follows:

For Sample 1 (3.5% Bitumen)

$$K = \frac{Q*L}{A*H*T} = \frac{1,923*7.8}{78.54*50*60} = 0.063659282 \text{ cm/sec.} = 55.002 \text{ m/day}$$

For Sample 2 (4% Bitumen)

$$K = \frac{Q*L}{A*H*T} = \frac{1,862.67*7.85}{80.12*50*60} = 0.060833581 \text{ cm/sec.} = 52.56 \text{ m/day}$$