Evaluation and Performance of Fly Ash in Porous Asphalt by Using Two Sources of Asphalt Binder

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Abstract: Porous asphalts are laterally followed in different applications especially in parking area, light road traffic, walkways, etc. The study of its properties is necessary due to stability and durability. The objective of this study is to evaluate various approaches to improve the durability and strength of the porous asphalt through laboratory testing. Porous asphalt specimens were prepared using two types of binder's sources: Lanaz refinery from Erbil city symbolled (A) and Phonix refinery from Slemani city symbolled (B) have penetration grade 40-50. Fly ash was utilized in the porous asphalt as an alternative admixture to replace filler (limestone powder) used in dry process. Mixtures forms of 4, 6, and 8% of fly ash replacement. Laboratory tests, including permeability test, Marshall Stability and flow test, volumetric of Marshall, and low temperature cracking test, were conducted. It is found that replacing 6% of fly ash significantly improved the overall performance of the porous asphalt mixtures. Fly ash improves stability and durability of the mixture more than limestone powder (filler).

Keywords: Porous Asphalt, Fly Ash, Permeability, Marshall Stability, Temperature Susceptibility

1. Introduction

Porous asphalt mixture or Open Graded Fraction Course (OGFC) is a new generation, which differs from conventional dense asphalt mixtures. It has limited amount of fine aggregate that is used to allow water to move through the asphalt layer. Open graded pavements are highly effective in decreasing pollution in runoff of water storm from pavement surface (Huber, 2000). However, the average service life of porous asphalt mixtures is limited to around 10–12 years or even shorter compared to the conventional dense graded asphalt mixtures that have a service life of about 18 years (Mo, 2010). Nevertheless, using open graded mixtures on the highway surface can enhance the ride quality for drivers during rainy weather by reducing skidding, spraying, and hydroplaning, as well as improving night visibility by eliminating the light reflecting on the roadway surface (Hsu, Chen et al. 2010). Commonly, the porous asphalt pavement is generally limited to the function of walkway, eco-park, parking lot and for light traffic areas (Isenring, 1990).

To seek the large porosity and the excellent ecological functions (reduction of noise, drainage, skid resistance, etc.), usually a little amount of mineral powder filler has been used in the design of mixture. Hence, it trends to the raveling distress at an early life step (Isenring, 1990). Porous asphalt mixtures were usually designed with an air voids about 16% to generate permeable structure for water drainage, which leads to excellent functionality of permeability and friction. However, the large amount of air voids (pores) dramatically reduces the strength and durability of porous asphalt pavement which is reflected by its vulnerability to rutting and raveling, that is, the loss of stone from the pavement surface (Zhang, 2018).

Furthermore, an aggregate gradation is one of the factors that determines the characteristics of the air voids formed within the porous mixture (Isenring, 1990). In addition, the selection of gradation materials is one of the aspects that resists to surface failure of porous asphalt with proper mixture design, good construction and adequate of structure thickness design. The resistance of the porous asphalt surfaces to failures depends upon proper gradation selection of materials, good mixture design, proper construction and adequate structural thickness design. It has long been accepted that filler plays a massive role in the behavior of porous asphalt mixtures.

Therefore, laboratory investigation is an approach to evaluate porous asphalt mixtures by utilizing fly ash as an alternative of filler in two different asphalt binder sources form Erbil and Suleimani in Kurdistan region, by examining the mixtures' air void properties using volumetric calculation and correlates with their permeability performance. The major cause of the raveling and rutting is the temperature sensitivity and a lack of adhesion of asphalt mortar, especially under repeated heavy load from vehicles (Zhang, 2018). However, the indirect tensile strength and resilient modulus of porous asphalt mixture are usually reduced than those of the traditional dense asphalt (Gemayel & Mamlouk 1988). Using modified binders and adding additives are the common methods to improve the performance of porous asphalt. The effects of all these additive materials are constantly two sided factors. First it improves the mixture's performance, and secondly might lower its performance beside of other aspect. Therefore, carrying out a research is necessary to understand the conditions of using various additives. The effects of types of binder source and fly ash as an additive on the mix's performances, such as Marshall Stability, Marshall Flow, low-temperature cracking resistance, and permeability, were investigated in this study.

2. Materials and methodology

2.1 Materials

The different locally asphalt binder from Kurdistan region were used in this study, and they are described in the following sections:

2.1.1 Asphalt binder

According to the data and results of previous studies, asphalt binder is one of the most important factors affecting the performance of open graded asphalt (Ni, 2003; Rongsheng 2008). Two types of asphalt binder sources (40-50) penetration graded were used in this study. It was obtained (Lanaz refinery) from Erbil city, and (Phonix refinery) from Slemani city. The physical properties of the asphalt cement are presented in Table (1).

Table 1: Physical properties of the asphalt binder sources (A, and B)

Property	Unit	Source A*	Source B**	Spec.
Penetration (25 c, 0.1mm)	0.1 mm	43	47	40-50
Ductility (5 c, cm)	cm	>150	>150	>100
Softening Point. Ring and Ball test	˚C	53	50	49-60
Viscosity at 135 ˚C		0.448	0.437	
Flash and Fire Point Test	˚C	250	265	>230
Loss on Heating	%	0.30	0.42	
Specific Gravity	kg/ cm3	1.0604	1.0550	

Where: *Source A, from Lanaz Refinery –Erbil. **Source B, from Phonix refinery-Sulemani. Note: Heating temperature of mixing is 163 ˚C

2.1.2 Aggregate

The crushed coarse aggregate is brought from Salaye quarry in Erbil. It consists of hard, strong, durable pieces, free of coherent coatings. The physical properties of the coarse aggregate are shown in Table (2).

Table 2: Physical properties of aggregate

Test	Test Value	Standard	Specification
Bulk Sp. Gravity	2.652	ASTM C127-04	
Apparent Sp. Gravity	2.784	ASTM C127-04	
Los Angeles Abrasion	22%	ASTM C 131	≤ 40 %
Impact Value	6%	ASTM D5874	≤ 30%
Water Absorption	1.75 %	ASTM (C-127)	≤3%

2.1.3 Fly ash (Additive) Replacing Filler

Fly ash, as the most commonly used supplementary cementitious material in construction services, is a byproduct of the combustion of pulverized coal in electric power generating plants. Most of the fly ash particles are solid spheres and some are hollow ecospheres. The particle sizes in fly ash vary from less than 1 μm (micrometer) to more than 100 μm with the typical particle size measuring less than 20 μm. Only 10% to 30% of the particles by mass are larger than 45 μm. Fly ash color is gray as shown in figure (1).

Figure 1: Fly ash powder additive

2.2 Methodology

2.2.1 The Selection of Gradation

Figure (2) shows gradation of porous asphalt used in different countries and agencies, with different ranges of gradation. Sometimes it is possible to reach differences of about 5% in the voids in total mix VTM for two similar gradation conditions (Mallick, 2000; Ameri & Esfahani 2008). The physical properties of the utilized aggregates were presented in Table (2). In this study the selection of gradation of aggregate was taken by more than 40 trials which were considered between NAPA and other countries' gradations as presented in Table (4).

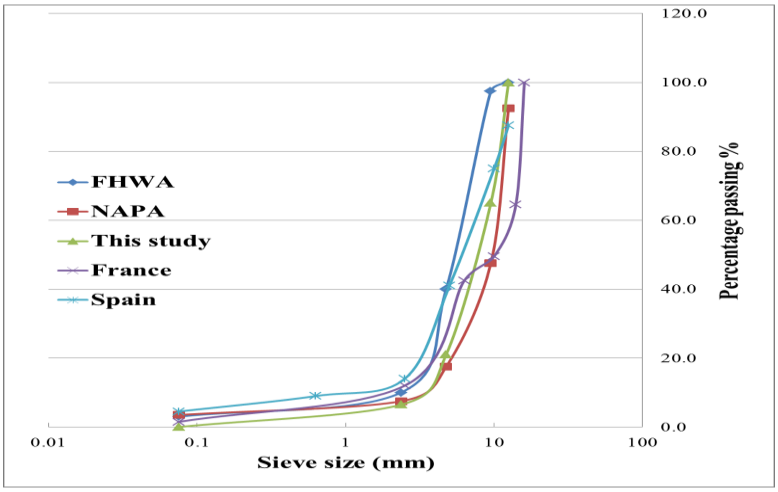

Figure 2: Aggregate gradations for porous asphalt mixtures between some countries and agencies

Table 4: Aggregate gradation evaluated in this study

sieve size (mm)	% passing
12.5	100
9.5	65
4.75	21
2.36	6
1.7	3
0.075	0

2.2.2 Study Testing Program of Porous Asphalt

Asphalt content range usually 3.5 to 6.5% is a proper content in gradation to determine the optimum binder content (Taute, 2001). In this study asphalt content and gradation of aggregate were taken more than 40 trials to optimize results. The whole testing program was conducted on specimens prepared at 4.5% of asphalt binder content. The preparation of asphalt concrete mixture was scheduled as below:

1. Selecting suitable aggregate gradation.
2. Preparation of asphalt concrete mixtures at asphalt content of 4.5%.
3. Preparation of asphalt concrete mixtures, asphalt content (4.5%) and fly ash (4, 6 and 8%) replacing filler by total weight.
4. Prepare (3) samples for each case totally (24) to determine permeability efficiency (K value) by using falling head permeability test.
5. Preparation of three groups of Marshall Specimens. Each group included 3 samples for Marshall Stability-flow test utilizing 4, 6, and 8% of fly ash additive for each binder sources.
6. Preparation of two groups of Marshall Specimens to study the effect of low temperature cracking and tested by indirect tensile test. In two different temperatures (25, and 60°C) flowing (3) specimens for each case totally (48) samples were prepared.

2.2.3 Study Tests

2.2.3.1 Permeability Test

The permeability test of all of the specimens was measured using the falling head procedure previously used to measure the permeability coefficient of porous asphalt mixtures (Mansour & Putman 2012; Wurst & Putman 2012).

The first step to prepare a sample was to wrap the specimen in plastic wrap around the sides to force the water to exit through the bottom of the specimen instead of outer of the perimeter of the specimen. After that a piece of clear tape was placed along the top of the specimen and folded over with the sticky side facing out so that once the specimen was in the stand pipe, water could not flow between the specimen and standpipe. Accordingly, the specimen was placed into the standpipe as shown in Figure

(3) and plumbers putty was applied to the outer edge of the tape to prevent any water leakage between the standpipe and the specimen (Lyons & Putman 2013).

The water outlet was located at the same elevation as the top of the specimen and the permeameter setup was leveled. After the specimen was secured in the standpipe, the specimen was initially saturated with water by filling the outlet pipe. The standpipe was then filled with water to approximately 300 mm above the top of the specimen, and the valve at the bottom of the specimen was opened to allow the water to flow through the specimen (Lyons & Putman 2013).

The time required for water to fall from a level of 200 mm above the specimen (h1) to 50 mm above the specimen (h2) was recorded using a stopwatch and repeated four times per specimen. The average time (t) was then used to determine the permeability of each Marshall sample by using Eq. (1), where A is the cross sectional area of the specimen in cm, a is the cross sectional area of the stand pipe, and L is the height of the specimen.

Permeability (K value) $$K = \frac{aL}{At} \ln\left(\frac{h1}{h2}\right) \quad [1]$$

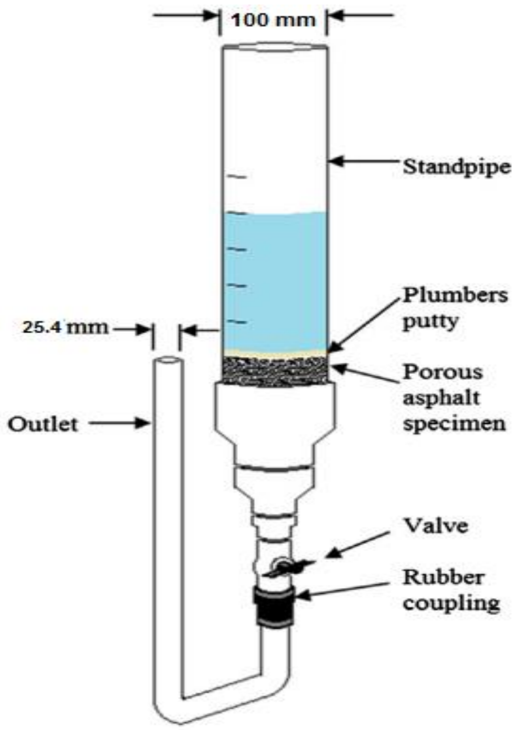

Figure 3: Permeability test schematic (falling head procedure)(Lyons & Putman 2013)

2.2.3.2 Resistance to Plastic Flow of Asphaltic Mixtures (Marshall Method)

ASTM, D-1559 method has been used which covers the measurement of the resistance to phasic flow of cylindrical specimens of asphalt paving mixture loaded on the lateral surface by means of Marshall apparatus. The prepared mixture is placed in a preheated mold of (4) in. (101.6mm) in diameter by (3) in. (76.2 mm) in height, and compacted with 75 blows/side with a hammer of 10 Lb. (4.536 Kg) sliding weight, and a free fall of 18 in. (457.2 mm) on the top and bottom of each specimen. The specimens are then left to cool at room temperature for 24 hours.

Marshall Stability and flow tests were performed on each specimen according to the method described by ASTM, D-1559. The cylindrical specimen is placed in water bath at 60 ˚C for (30-40) minutes, then compressed on the lateral surface with a constant rate of (2) in. /min. (50.8 mm/min) until the failure is reached. Three specimens for each percentage of fly ash for two binder sources were prepared and the average results are reported.

2.2.3.3 Resistance to Low-Temperature Cracking & Temp Susceptibility of Asphalt Mixture

ASTM, D-4123 method which determines the indirect tensile strength of asphalt concrete mixture has been used for this purpose. The specimens were prepared in according with ASTM-D-1559 left to cool at room temperature for 24 hours and then placed in a water bath at the specific test temperature for 15 minutes before testing. The loading strips were placed on the specimens and then tested for indirect tensile strength at a rate of 2 in. /min. (50.8mm/min.) until recording the maximum load resistance. Three specimens for each mix combination were prepared and the average results were reported. For the purpose of low temperature cracking, 25˚C test temperature was obtained. To calculate the degree or the value of temperature susceptibility, a different test temperature of 60˚C was obtained; the result is shown in Table (5).

The tensile strength St was calculated as follows:

$$\mathrm{St} = \frac{2\mathrm{Pulti.}}{\pi\ \mathrm{tD}} \quad (\mathrm{Kg/cm2}) \qquad [2]$$

Where Pulti. =Ultimate applied load (Kg); t=thickness of the specimen (cm); D=diameter of the specimen (cm), The temperature susceptibility T.S. was determined as:

$$T.S = \frac{STi-STj}{j-i} \quad \left(\frac{\mathrm{Kg/cm2}}{{}^{\circ}\mathrm{C}}\right) \qquad [3]$$

Where STi= Tensile strength at (i ˚C) temperature, in this work i= 25 ˚C; STj= Tensile strength at (j ˚C) temperature, in this work j= 60 ˚C

3. Result and Discussion

3.1 Permeability

Figure (4) shows permeability results of each mix design through the falling head test method. The addition of fly ash had a tendency to reduce the mix permeability for both binders' resources. The results show that the mixes without fly ash (mixes fly ash 0%) had the highest permeability values and the results were statistically similar for two types of asphalt binder which was (0.502, 0.414 cm/sec) for (B) Phonix and (A)Lanaz respectively. While the reducing three mixtures had relatively different in adding fly ash additive from (4, 6, and 8%), there were differences in permeability. Finally, the addition of fly ash resulted in a permeability reduction of the porous asphalt mixes. But still it works as porous material to serve in environment direction.

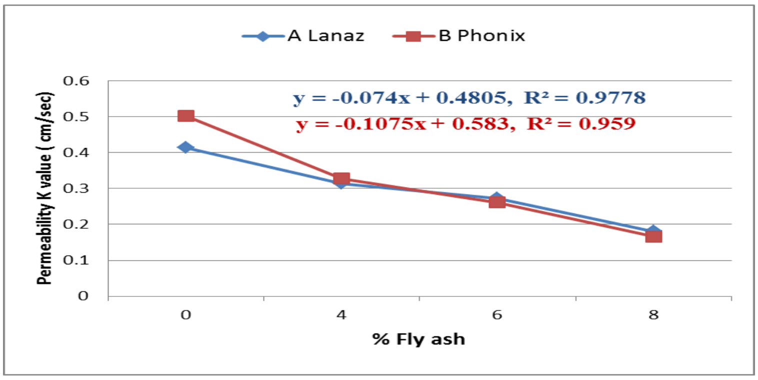

Figure [4] Percentage of Fly ash versus Permeability value (K)

3.2 Indirect Tensile Strength and Moisture Susceptibility (Indirect tensile strength Method)

Results of the indirect tensile strength test are shown in Table (5) and Figure (5). The designed mixes from susceptible moisture mostly were based on the strength of indirect tensile or tensile strength ratio (TSR), in accordance with SC-T-70. For some agencies the minimum value is typically 70%(Putman & Kline 2012). This test was used to ensure whether each mix was susceptible to moisture induced damage, also to compare the indirect tensile strengths of each mixture, which could be an indicator of the cracking resistance of the porous pavement mixtures. The results showed that fly ash increase temperature susceptibility.

Table 5: Effect of Fly ash as additive using two source of binder on indirect tensile strength test, according ASTM (D4123)

additive	%	Source (A) Lanaz			Source (B) Phonix		
		ST j=60 °C (Kg/cm2)	ST i=25 °C (Kg/cm2)	T.S (A) $(\frac{Kg/cm2}{°C})$	ST j=60 °C (Kg/cm2)	ST i=25 °C (Kg/cm2)	T.S (B) $(\frac{Kg/cm2}{°C})$
Fly ash	0%	4.947	20.994	0.458	3.195	19.625	0.469
	4%	4.947	21.907	0.485	2.967	21.564	0.531
	6%	6.088	24.645	0.530	4.564	22.591	0.535
	8%	7.987	26.927	0.541	5.705	24.759	0.544

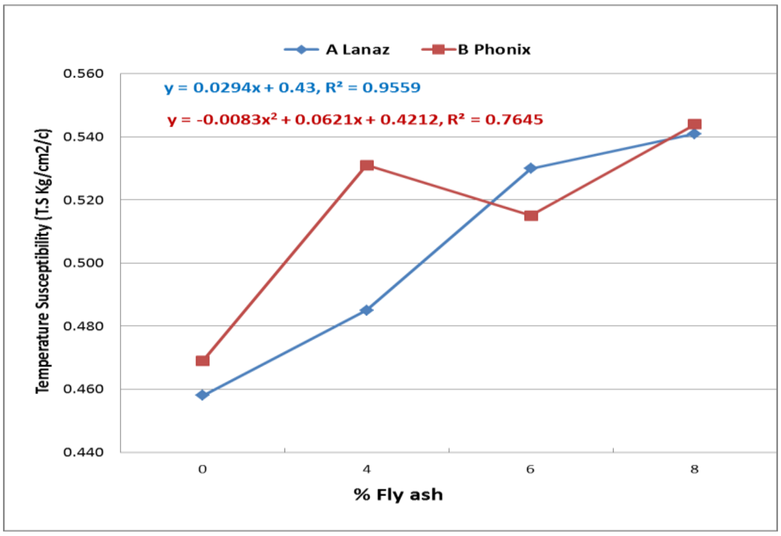

Figure 5: Fly ash content versus Temperature susceptibility

3.3 Marshall Stability and Flow

3.3.1 Stability

Stability refers to the ability of the paving mixture to offer resistance to deformation under repeated loads. Figure (6) shows stability as a function of Fly ash content. The stability still remains for both types of asphalt binder at 0, 4 % of fly ash, then when the percentage exceeds up to 6, and 8% the stability increases for both types Lanaz and Phonix asphalt. Lanaz Asphalt when utilized 8% fly ash reaches approximately 9 KN, but for Phonix asphalt the stability value for 8% fly ash content was 6.25 KN and these results are familiar to ASTM standard. This maximizing value of stability may be due to physical properties fact that Lanaz asphalt binder penetration was low, but the ductility for two types binder were still more than 100cm. Besides, 8% fly ash was reported the worst permeability value.

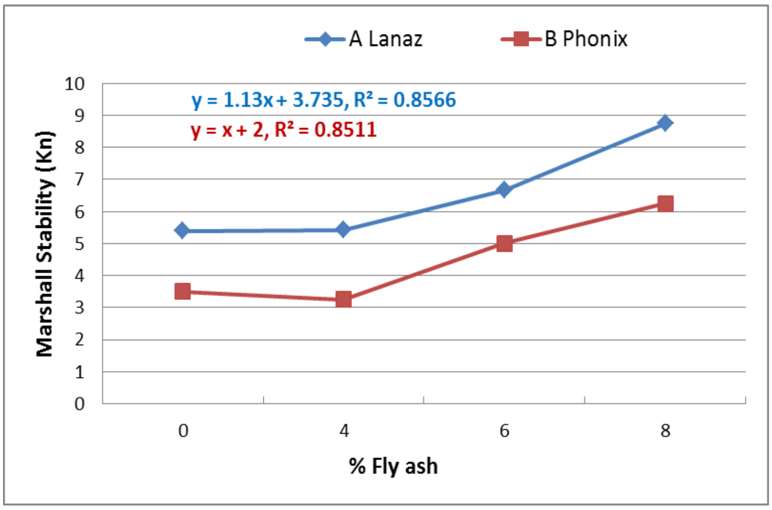

Figure 6: Marshall Stability versus % Fly ash

3.3.2 Flow

Flow of Marshall was measured simultaneously with Marshall Stability; flow measured the deformation of the specimens while loaded. The flow values for the pervious asphalt with Fly ash addition for both types of asphalt binder were presented in Figure (7). The flow value for 0% fly ash content was 3.3, 4.6mm for Lanaz and Phonix asphalt. An increase in fly ash content resulted in an increase in flow up to value of 8% fly ash content approximately (4.6 mm).

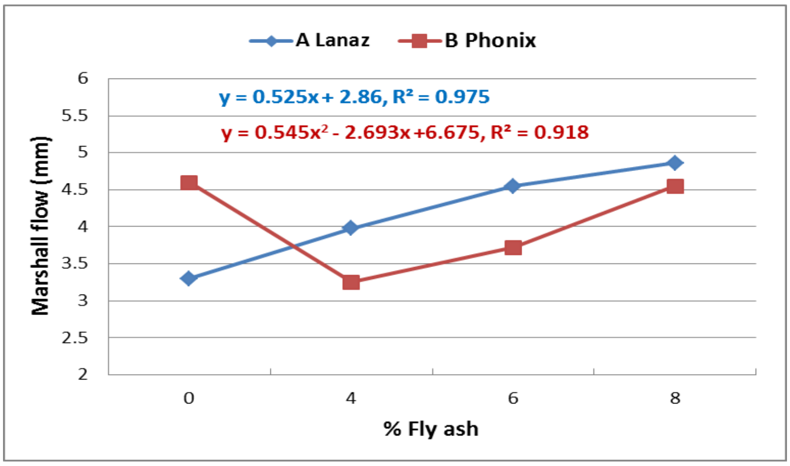

Figure 7: Marshall Flow versus % Fly ash

3.4 Volumetric Calculation

3.4.1 Total Void in Mixture (VTM)

VTM shows the percentage of voids in total mixture. VTM affects the durability and performance of the aggregate asphalt mixture. As shown in Figure (8), for source (A) the highest VTM value was at 4% fly ash (18.76%) and the lowest average VIM value at 8% of fly as (12.88% voids). Also source (B) at (0, 4, and 6%) fly ash content results were (20.43, 18.77, and 14.88%) respectively. There was a big variation in VTM with fly ash content. These results of VTM were obtained in this research, compared to some previous studies, are greater and more effective (Ameri & Esfahani 2008; Eka Putri & Vasilsa 2019). Generally fly ash reduces VTM which is the point to decrease the K value.

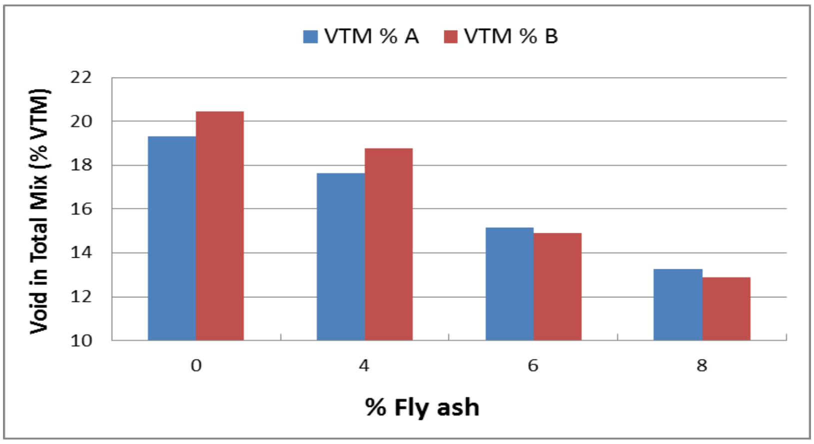

Figure 8: Void in Total Mix VTM versus % Fly ash

3.4.2 Void in Mineral Aggregate (VMA)

Similarly, it was predicted that VMA would be affected by adding fly ash additive and changing asphalt binder source, as shown in Figure (9). The highest value of the VMA was 26.76% at 0% fly ash content, and the lowest VMA value was at 20.52% at 8% fly ash content for Lanaz asphalt binder. Our study results of VMA are in agreement with and similar to those of Eka Putri and Vasilsa (2019).

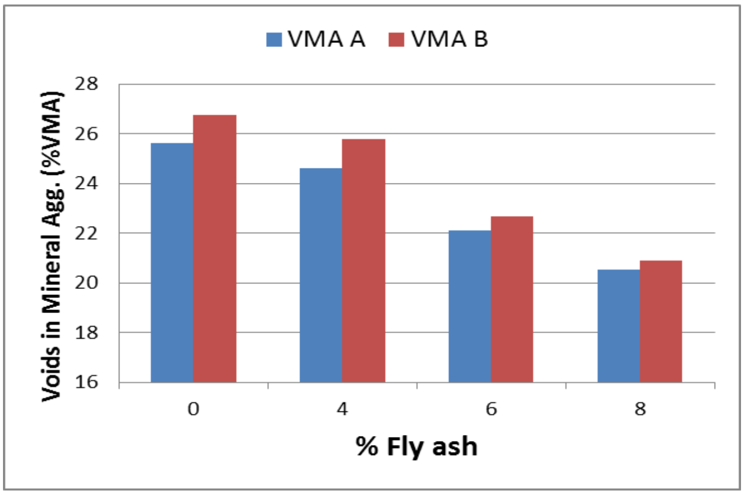

Figure 9: Voids in Mineral Agg. VMA versus % Fly ash

3.4.3 Void Filled with Asphalt (VFA)

The highest value of VFA of 38.29% is found at 8% fly ash content for Phonix (B) asphalt and the lowest VFA value of 23.63 % at 5.5% filler content without fly ash for Phonix asphalt, as shown in Figure (10). This variation is also expected as VFA trends to increase dramatically when the fly ash content is varied. As can be seen in Figures (6, and 10) gradually increasing VFA% means better stability.

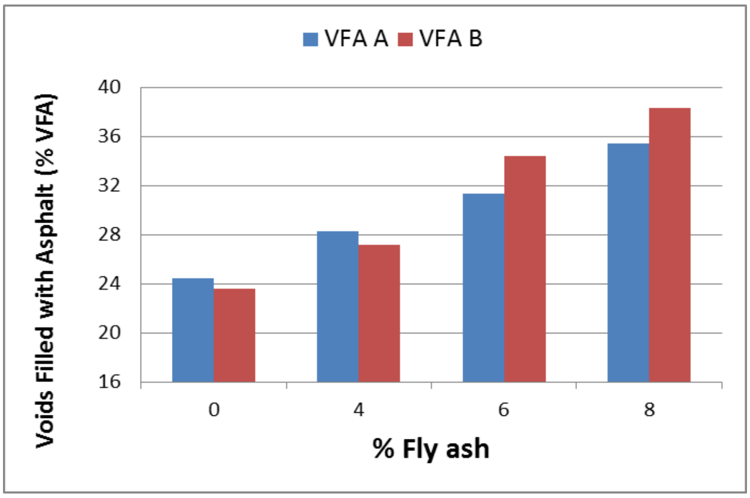

Figure 10: Voids Filler with Asphalt VFA versus % Fly ash

3.4.4 Maximum Specific Gravity of Asphalt Mix (Gmm), Apparent Specific Gravity of Asphalt Mix (Gmb)

Table (6) presented the results and properties of the porous asphalt mixtures, the test results are averaged from Marshall Specimens, it seems that the (Gmb) for both sources as shown in the table below increased by utilizing fly ash additive. But inversely to (Gmb), the results of (Gmm) slightly reduced by adding fly ash.

Table 6: Summary of mixture volumetric properties

Asphalt	%Fly	Gmb	Gmm	VTM %	VMA%	VFA%
Source (A)	0	2.1312	2.6524	19.343	25.6105	24.474
	4	2.1412	2.6403	17.652	24.6001	28.243
	6	2.1952	2.6314	15.175	22.1011	31.338
	8	2.2245	2.6248	13.258	20.5298	35.422
Source (B)	0	2.122	2.6627	20.437	26.7615	23.632
	4	2.131	2.6512	18.769	25.7803	27.195
	6	2.203	2.6375	14.884	22.6947	34.416
	8	2.221	2.6325	12.889	20.8886	38.296

(Gmb = Apparent specific gravity of asphalt mix, Gmm =Maximum specific gravity of asphalt mix, VTM=Voids in total mix, VMA=Voids in mineral aggregate, VFA=Voids filled with asphalt, ps = Percent of the total aggregate (ps=95.5%)

4. Conclusion

Comprehensive laboratory tests were investigated on the porous asphalts with various binders with fly ash as an additive replacing filler in this study. Based on the test data analyzed and discussed, the following conclusions can be obtained:

1. Fly ash in replacing filler in different rates changes the porous asphalt properties.
2. 6% fly ash showed better results for stability, it was increased about (20 and 30%) for source A and B respectively in compared with zero fly ash content.
3. Permeability decreased approximately (34 % and 48%) for both asphalt sources when fly ash content 6% was compared with fly ash rate 0%.
4. Temperature susceptibility increased approximately (13%) for two asphalt sources.
5. For finding allowable stability and permeability for porous asphalts, fly ash is solving the critical properties with suitable service life of porous parameters.
6. Asphalt binder source from Erbil city shows better results than Slemani's source asphalt bitumen.

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