

Enhancing Porous Asphalt with Fly Ash for Sustainable Development

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ABSTRACT

Porous asphalt pavement is a particular asphalt mixture made up of both fine and coarse aggregates bonded by a bituminous binder. Although it has a rougher texture, porous asphalt looks like conventional asphalt on the outside. In the past decade, porous asphalt pavement has gained popularity as a storm water best management practice and utilize similar mixtures as those used for open-graded friction courses. Additive materials such as fly ash, coal ash, and many more had been widely used successfully in the original specification of porous asphalt mixtures to improve their durability and rutting resistance performance. In this study, fly ash has been used to replace aggregate dust and the aggregate gradation limit in the porous asphalt mixture to determine the Optimum Bitumen Content (OBC) as well as to improve rutting resistance and durability. The OBC was then determined for all the mixes by Marshall Mix design. Laboratory specimens were prepared using 75 blows of the Marshall hammer per side. The OBC for the conventional porous asphalt mix with aggregate dust was found to be 6 percent, while the OBC for the modified porous asphalt mix with fly ash was found to be 5 percent. Rut depth for porous asphalt mixes with aggregate dust was lower (1.6 mm) compared with porous asphalt mixes with fly ash (1.93 mm). This indicates that the additive material could efficiently retain the binder in the mix. As a result, fly ash could be used as an alternative to aggregate dust in the porous asphalt mixture.

Keywords—Aggregate dust, Fly Ash, Marshall Mix Design, Optimum Bitumen Content, Porous Asphalt.

INTRODUCTION

Porous asphalt pavement mixtures are designed with an open graded aggregate to increase the number of permeable air voids, which allow water to penetrate through the voids, removing it from the surface of a roadway much faster than traditional dense-graded pavement [1]. Porous asphalt is often weak and breaks due to rutting behavior [2]. This failure occurs when the asphalt pavement cannot sustain continuously high traffic loads for a long period of time. The main cause of rutting is the low strength of asphalt pavement due to the poor physical strength of the materials. The tendency of the asphalt pavement to break during hot weather may cause premature failure of the mix. To overcome this problem, additive material is being used to replace the aggregate dust as the last aggregate gradation limit. Additive materials such as natural rubber have been widely used successfully in the original specification of the porous asphalt mixtures. However, the cost of rubber modified asphalt has been a long-term reason not to use it [5]. As an alternative to resolving this problem, fly ash, also a type of additive material, was selected in this study to be used for porous asphalt mixtures as a cost- and performance-effective solution.

Fly ash is a lightweight material that can be easily compacted; these properties can be useful in generating new technologies for the development of highway projects that could further provide monetary savings in transportation, construction, and material costs [3]. The use of fly ash in porous asphalt mixtures is worth investigating, as the availability of fly ash resources in Malaysia will result in a lower production cost for porous asphalt pavements. In addition, this material can provide an alternative, sustainable asphalt pavement material [3].

Hence, the main goal of this is to determine the Optimum Bitumen Content (OBC) as well as to evaluate the performance of a modified porous asphalt mix using fly ash as the last aggregate gradation limit, and to compare its performance with a conventional porous asphalt mix using aggregate dust as its last aggregate gradation limit.

METHODOLOGY

Sample Collection

In this study, the fly ash was chosen based on its own physical and chemical characteristics. Fly ash is a by-product from coal-fired electricity-generating power plants^[4]. The sample of fly ash was obtained at an electric power plant in Manjung, Perak, and it is shown in Figure 1.

Figure 1: Fly Ash powder



Sieve Analysis

The classification of aggregates is determined via sieve analysis. A mechanical sieve shaker can be used in the laboratory to determine the size of each aggregate by using the vibration method. Aggregates will be retained on the pan according to their pan size. The gradation of the combined coarse aggregate, fine aggregate, and mineral filler was chosen to conform with the appropriate envelope in accordance with PWD Malaysia's Standard Specification for Road Works (JKR/SPJ/2008)^[6]. Table 1 shows the aggregate gradation limits of the ACW14 mixture.

Table 1: Gradation Limits of Combined Aggregates

BS Sieve Size, mm	Percentage Passing by weight	
	Grading A	Grading B
20	—	100
14	100	85 – 100
10	95 – 100	55 – 75
5	30 – 50	10 – 25
2.36	5 – 15	5 – 9
0.075	2 – 5	2 – 4

Aggregate Test

In this study, several aggregate tests have been conducted. Water absorption, LA abrasion, LA impact, and flakiness index tests are among the aggregate tests that have been conducted to fulfil the objective of this

study.

Aggregate Grading

Based on the JKR Malaysia Specification gradation limit, a total weight of 1200g combined aggregate grading consisting of aggregate sizes 14mm, 10mm, 5mm, 2.36 mm, and 0.075mm was prepared.

Bitumen Content

The bitumen added to the mixture is fixed by referring to JKR Arahan Teknik Jalan (JKR/SPJ/2008-S4) ^[6]. The percentage of bitumen needed for the mixture varies from 4 percent to 6 percent, with an increment of 0.5 percent.

Sample Preparation

The porous asphalt mixtures were prepared in accordance with the Marshall method as specified in ASTM D1559. Samples were prepared by replacing the aggregate dust with fly ash as the last aggregate gradation limit. Three modified compacted samples are prepared for each bitumen content. Five bitumen contents are to be tested to get the OBC.

Marshall Mix Design

A Marshall method was used to obtain the volumetric properties such as bulk specific gravity, Marshall flow, Marshall stability, air voids, and voids filled with aggregate (VFA). This method is used for both conventional and modified porous asphalt mixtures. In addition, from this method, the OBC for varying percentages of bitumen content is also determined for both porous asphalt mixtures.

Performance Test

In this study, two performance tests were conducted: the binder draindown test and the rust susceptibility test. Binder Draindown Test was determined by placing the weight of loose porous asphalt mixture in a basket. For this study, the samples were prepared at optimal bitumen content. Meanwhile, for the rust susceptibility test, an automated pavement analyzer (APA) was used in accordance with AASHTO TP63 ^[7]. The test length was set to 8000 cycles.

RESULT AND DISCUSSION

Combined Aggregates Grading

Table 2 shows the tabulation of combined fine aggregates and coarse aggregate. The total weight of the combined aggregates graded is 1200g.

Table 2: Aggregate Grading for Porous Asphalt

BS Sieve	ACW14	% passing	% retained	Weight (g)	Accumulative Weight (g)
14	100	100	0	0	0
10	95 – 100	97.5	2.5	30	30
5	30 – 50	40	57.5	690	720
2.36	5 – 15	10	30	360	1080
0.075	2 – 5	3.5	6.5	78	1158
Pan	0	0	3.5	42	1200

Bitumen Content

Table 3 shows the percentage of bitumen content needed for porous asphalt mixtures. The percentage of bitumen content is in the range of 4 percent to 6 percent in increments of 0.5 percent.

Table 3: Percentage of Bitumen Content needed in Porous Asphalt Mixtures

Bitumen (%)	Weight of Bitumen (g)	Total Weight (g)
4.0	48	1248
4.5	54	1254
5.0	60	1260
5.5	66	1266
6.0	72	1272

Volumetric Properties

Table 4 shows the results of the volumetric properties of porous asphalt mixtures using material according to the Marshall method. Porous asphalt mixtures with aggregate dust contained higher values of air voids compared to the porous asphalt mixtures with fly ash. This might also be the likely cause of the higher flow for the aggregate dust, which is slightly above (3mm) the specification requirements. Moreover, the OBC for the porous asphalt mixtures with aggregate dust and fly ash was found to be 6 percent and 5 percent, respectively.

Table 4: Volumetric Properties of the Porous Asphalt Mixtures

Volumetric Properties	Porous Asphalt Mix Requirement	Conventional Porous Asphalt (Aggregate Dust)	Modified Porous Asphalt (Fly Ash)
Stability, N	Min 8000	12500	17900
Flow @ 3mm	2 – 4	3.0	0.773
Air Voids in Total Mix @ 21.5%	18 – 25	18.0	12.06
Optimum Bitumen Content (OBC)	5 – 6	6.0	5.0

Binder Draindown

Binder draindown was calculated as the percentage of the binder that drained out of the basket by using Eq. (1).

$$\text{Binder Drainage (\%)} = (C-B)/A \times 100 \quad \dots \text{Eq. (1)}$$

Where;

A = Weight of initial total sample (g)

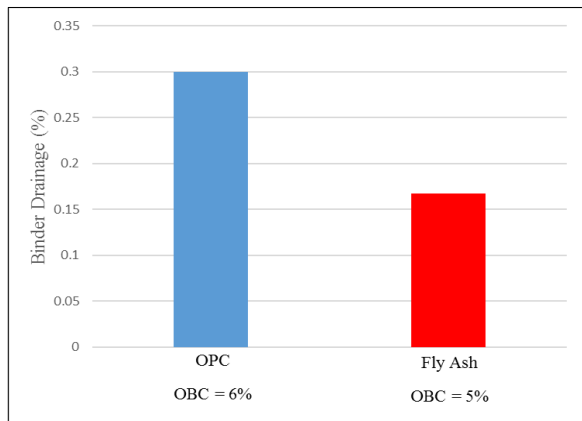
B = Weight of tray at starting time (g)

C = Weight of tray at final time (g)

The PWD Malaysia specification states that the maximum draindown value is 0.3% of the total mixture. The percentage of binder drainage for each porous asphalt mixture is presented in Figure 2. Both mixes with

aggregate dust and fly ash met this requirement with draindown values of 0.3% and 0.167%, respectively. The addition of additive material into the mix allows the asphalt to be more viscous and provides the ability to retain asphalt during the drain out process when temperature increases.

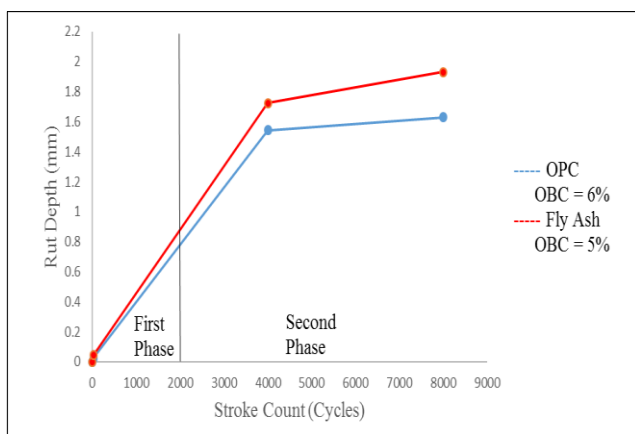
Fig. 2: Binder Draindown for Porous Asphalt Mixes



Rutting Test

Fig. 3 shows the results of the rutting test carried out using the APA. Based on the figure, rut depth for both mixes increases with the count of strokes under repeated passes of a loaded wheel. After the completion of 8000 cycles, the rut depth measured for aggregate dust is 1.6mm and for fly ash mix is 1.93mm. The higher rut depth value for aggregate dust is likely due to the higher value of bitumen content used in the mix.

Figure 3: Rut Depth using APA for both mixes.



CONCLUSIONS

Based on the result obtained, it was observed that the performance of the porous asphalt mixture was significantly affected with the addition of the selected material as a performance enhancer. Utilisation of selected materials in the mixture can affect the volumetric properties, binder drainage, and performance to resist rutting of the mixes. From the results of the laboratory work, the following conclusion can be made:

1. Modified porous asphalt mixtures using fly ash have a slightly lower OBC compared to conventional porous asphalt mixtures using aggregate dust.
2. Modified porous asphalt mixtures using fly ash show better ability to retain the binder draindown of the mixture compared to conventional porous asphalt mixtures using aggregate dust.
3. Aggregate dust shows higher resistance to rutting compared to fly ash due to the absence of mineral filler, which is Ordinary Portland Cement (OPC).

Therefore, it can be concluded that additive material such as fly ash could be an alternative material to replace the aggregate dust in porous asphalt mixes.

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