The Effect of Utilizing Fly Ash and Bottom Ash as a Replacement of Mineral Filler in Porous Asphalt Mixtures

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Abstract. In the past decade, porous asphalt pavements have gained popularity as a stormwater best management practice because this unique asphalt can reduce spray and splash in wet weather, consequently reducing hydroplaning and increasing visibility. However, despite porous asphalt benefits, there are still some weaknesses, such as short service life than dense-graded asphalt due to its lower durability and strength. Coal ash is one of the most abundant industrial wastes and may be harmful to living things and human life if disposed of wrongly. The combustion of coal in the furnace in the power plant produces coal ash, consisting of fly ash and bottom ash. Hence, in this research, utilizing fly ash (class F) and dry bottom ash as a replacement of mineral filler to reduce the drainage value and improve the strength of porous asphalt mix was investigated. Laboratory specimens were prepared using 50 blows of Marshall Hammer per side by the Marshall mix design method. The bituminous binder used was performance grade PG 76, which complies with AASHTO Standard M320-02. The percentage of binder content in the range of 4.0\% - 6.0\% in increments of 0.5\% was used to determine the Design Binder Content (DBC). The mix with both ashes was found to be 5 per cent of DBC. The DBC value for both mixtures was then used to evaluate the mixtures' performance, which went through a binder drainage test, and rutting test. The performance results were then compared with the control porous asphalt mix using mineral filler. The control mixture and both modified mixtures show drain down values of 0.3\%, 0.262\%, and 0.167\%, respectively. The replacement of both materials into the control mixture indicates that fly ash and bottom ash could increase the binder's heat resistance and efficiently retain the binder in the modified mixtures. Meanwhile, after the completion of 8000 cycles in the rutting test, it could be seen that the rut depth measured for the mix with mineral filler was 1.6\,mm, 1.93\,mm for the mix with fly ash, and 2.04\,mm for the mix with bottom ash. The bottom ash mix's higher rut depth value is likely due to the bottom ash characteristic with higher unburned carbon content, thus decreasing the strength mix. It is concluded that an investigation between both ashes in porous asphalt has the potential for the road industry in the future, leading to sustainable highway development.

1. Introduction

Porous asphalt pavement mixtures are built with an open-grade aggregate to increase the number of permeable air voids, allowing water to infiltrate the voids, eliminating them from the road surface much faster than conventional dense pavement [1]. Porous asphalt is, however, quickly destroyed by rutting and binder drainage [2]. To overcome this problem, fly ash and bottom ash replace mineral filler to reduce the drainage value and improve the strength of the porous asphalt mix.
Coal combustion in power plant furnace creates coal ash, consisting of fly ash and bottom ash. Fly ash is the lighter ash transported with the exhaust gases into the furnace, gathered by ash precipitators. Meanwhile, bottom ash is the heavier ash that falls through the bottom of the furnace and finally collected in the hopper [3]. Coal waste is generated during the coal burning process for electricity generation, which includes coal ash in the 75-85% fly ash (FA) and 15-25% bottom ash fraction (BA) [4]. Continuous ash production affects in expanding ash dumps and even pose serious health threats.

Hence, this research's main goal is to investigate the effect of utilizing fly ash and bottom ash as a replacement of mineral filler in porous asphalt mixtures and to compare its performance with a control porous asphalt mix. At the end of this research, the investigation had reduced the drainage value, indirectly protect the environment by reducing waste material and save natural resources in Malaysia.

2. Experimental
An operational framework for all the laboratory processes and procedures of this research is explained in detail. Information and material were collected before the work plan for the laboratory process were conducted. All the data and information related to the research were collected from wide and various sources. Figure. 1 shows an operational framework for this research.

![Figure 1. An operational framework for this research.](image)

In this research, the fly ash and bottom ash samples were obtained from the electric power plant at Manjung, Perak. It is one out of the four thermal power plants that utilize pulverized coal in electricity generation, with others being in Kapar, Selangor, Pontian, Johor, and Jimah in Negeri Sembilan. Fly ash (class F) and dry bottom ash were dried first in an oven to reduce moisture content. Bottom ash was then ground with a ball mill and then sieved with a BS 75 µm sieve. Particles that did not pass the BS 75 µm sieve were re-milled and sifted continuously.
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The aggregate classification was determined by sieve analysis. In the laboratory, a mechanical sieve shaker was used to determine the size of each aggregate. Aggregates will retain on the pan according to their pan size. The gradation of the combined coarse aggregate, fine aggregate, and, together with at least 2% mineral filler, should conform to the appropriate envelope by PWD Malaysia's Standard Specification for Road Works (JKR/SPJ/2008). Table 1 shows the gradation limits of combined aggregates. A few aggregate tests were conducted during this research to achieve and fulfil physical and mechanical quality requirements.

| 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                         | 5-10      |
| 0.075            | 2-5                          | 2-4       |

With high air voids and open-graded aggregates, high binder content is necessary to ensure mix integrity, increase oxidation and ravelling resistance and improve durability [5]. The percentage of binders content between 4.0% and 6.0% in increments of 0.5% is required to prepare mixtures. The porous asphalt mixtures were prepared using the Marshall design method as defined in ASTM D1559[6]. The modified mixtures were prepared by replacing the mineral filler with fly ash (class F) and dry bottom ash. The mixtures were poured into preheated Marshall moulds and compacted at 50 numbers of a blow on each side. Each compacted samples were kept overnight to be cooled at room temperature. In this research, the control and modified porous asphalt samples were subjected to the volumetric analysis to determine the DBC.

In this research, two performance tests were conducted: the binder drain down test and the rutting test. The mixtures were prepared at design binder content to perform both tests. The drainage was determined by placing the porous asphalt mixtures in the wire basket without consolidating them or disrupting them. The filled basket was placed over a pre-weighted stainless steel plate in the oven for three hours at a temperature of 170°C. After three hours, the filled basket and the stainless steel plate

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**Figure 2.** Fly ash powder.
were removed and the final mass of the plate recorded. The drain of the binder was measured as the percentage of the binder drained from the basket.

The samples were prepared and compacted to obtain 20-25% of air voids using a gyratory compactor. An Asphalt Pavement Analyzer (APA) is used to conduct the AASHTO TP63 rutting test [7]. The temperature was set, and samples were preheated for 6 hours in the calibrated APA test chamber. The temperature of the test depends on the climate data for the location of the mixture to be located and is typically similar to the highest predicted pavement temperature [8]. The samples were then loaded into the chamber, and the test duration was set to 8000 cycles, and the APA loading began. Sample deformation was then recorded as rutting value.

3. Results and discussions

3.1. Volumetric properties

Table 2 shows the volumetric properties for porous asphalt mixtures according to the Marshall mix design method. Porous asphalt mixture with the bottom ash contained less air void than other porous asphalt mixtures. This condition might also be the likely cause of the angular and rough texture of bottom ash itself. Moreover, the design binder content for both modified mixtures was 5 per cent compared to the control mixture, which indicates 6 per cent.

| Volumetric Properties | Control Porous Asphalt | Porous Asphalt with Fly Ash | Porous Asphalt with Bottom Ash |
|-----------------------|------------------------|----------------------------|-------------------------------|
| Stability, N          | 22500                  | 17900                      | 12070                         |
| Flow, mm              | 3.0                    | 2.77                       | 2.63                          |
| VTM (%)               | 18.0                   | 12.06                      | 9.73                          |
| DBC (%)               | 6.0                    | 5.0                        | 5.0                           |

3.2. Binder drain down test

Drainage happens when there is a higher temperature, lower viscosity, resulting in more drainage. The binder's propensity to drain during hot weather can cause premature mix failure [9]. Binder drainage was investigated in the mixes to prevent premature failure in this research. Control mixture and modified mixtures (fly ash and bottom ash) display drainage values of 0.3%, 0.262%, and 0.167%. The replacement of both materials into the control mixture indicates that fly ash and bottom ash could increase the binder's heat resistance in the modified mixtures, which leads to a reduction in binder drainage. Figure 3 shows the percentage of binder drainage per control and modified porous asphalt mixtures.

![Figure 3. Illustration of recorded binder drainage data.](image)
3.3. Rutting test
The rutting test was conducted to simulate the behaving of the rut depth on the asphalt pavement. Under the repeated cycle of the loaded wheel, the value of the rut depth recorded for both mixtures increased with a stroke count [10]. After completing the cycles, the rut depth recorded for the mix with mineral filler was 1.6mm, 1.93mm for the fly ash mix, and 2.04mm for the bottom ash mix. The higher rut depth value of the bottom ash mix is possibly due to the bottom ash characteristic with higher unburned carbon content, thus reducing the strength mix. Figure. 4 illustrates rutting test results conducted using the Automated APA (Automated APA) device.

![Figure 4. Illustration of recorded rut depth data.](image)

4. Conclusion and recommendation
Based on the results obtained, the efficiency of the modified porous asphalt mixtures was significantly affected by adding selected material as a performance enhancer. Volumetric properties, binder drainage and performance of rutting resistance can be seen influenced by materials chosen in the mixtures. Based on the analysis and research conducted, the following conclusion can be drawn:

- Modified porous asphalt mixtures have a slightly lower DBC compared to controlled porous asphalt mixtures using mineral filler.
- Modified porous asphalt mixture using bottom ash is more capable than control and modified porous asphalt mixture using fly ash to retain binder drainage. However, both modified mixtures meet the requirements of the Malaysian Public Works Department, which shall not exceed 0.3 per cent by weight of the total mix.
- Controlled mixture using mineral filler shows more excellent rutting resistance than modified mixtures. However, for both modified mixtures, the rut depth value remains a distant maximum rut depth of 20 mm.

As a result, fly ash and bottom ash could be an alternative material to replace mineral filler in porous asphalt mixtures. Even as porous asphalt control has higher stability and better rutting resistance, rational use of both ash in porous asphalt as the results show improvement in binder drainage durability, which could minimize asphalt failure and damage. But, further research is required to support this conclusion, to see the reaction of unburned carbon content that can influence the strength of the pavement.

5. References

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