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# The Practical Use of Palm Oil Fuel Ash as a Filler in Asphalt Pavement

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**Abstract**

*Palm oil industry currently has been seen as an important role in Malaysia's economy. However, it also driving towards increasing of waste such as empty fruit bunch, mesocarp fibre, palm oil mill effluent (POME), and palm oil fly ash (POFA). POFA is identified as a material that shows good potential to be used as filler in asphalt mixture. Intensive literature showed that most of research primarily used POFA in concrete material, and limited in pavement material. Therefore, in this study, the potential of POFA in asphalt concrete was evaluated as an alternative initiative to promote waste recycling in road construction industry. POFA was incorporated as filler (material passing 75μm) into a mixture design ACW20 with varied amount - (0, 3, 5, 7 and 10% by weight of total aggregate) and bitumen content 5.1%±0.5. The specific gravity properties of each amount of POFA were assessed to be used during Marshall volumetric properties. These materials then were analyzed using Marshall stability and resilient modulus. A correlation derived as the specific gravity decreased, the Marshall stability decreased and resilient modulus increased compared to conventional asphalt mixes. Based on the results also, the appropriate amount of POFA found as 3% with the optimum asphalt content 5.1%. The laboratory results showed that the resilient modulus of asphalt mixture was improved with the certain amount of POFA and indicated that POFA have the good potential as alternative filler material in asphalt mix.*

Keywords: Palm Oil Fuel Ash (POFA), resilient modulus, mineral filler

## 1.0 INTRODUCTION

Agriculture is an important sector contributing to Malaysia economy. The main crops such as oil palm, rubber and cocoa have dominated in this sector for export. On the other hand, agriculture also produced the main source of solid waste and following then by industrial, municipal and mining sources. Oil palm also produced a few types of wastes such as empty fruit bunch, mesocarp fibre, palm oil mill effluent (POME) and palm oil fly ash (POFA). POFA is the grey stuff with seem black which an agro-waste resulting from the incineration process at temperature about 800°C - 1000°C of oil palm residue [1]. In January 2012, production of crude palm oil is recorded as 1.287 millions tonnes and the solid waste generated by this industry is expected more than 0.5 millions tones especially POFA that abundantly generated [2]. The large quantity of these wastes can create an environmental problem if they are not dispose in proper way. Therefore, as a way to encourage recycling in pavement engineering, the POFA was integrated in asphalt mixture. However, the POFA is widely used in concrete technology. This is because concrete is a material that have major problem with low tensile strength compared to compressive strength [1].

In pavement, aggregate was put together with bitumen to form road that can bear the burden of traffic and have the quality which has been prescribed. This pavement comprised of several overlap layer make selected material from that correspond. It consists of aggregate consumption and cement and it is increasingly attract the attention of the public especially in road construction project. Much alternative material is developed to reach the usage of new aggregate in pavement such as fly ash [3-4], waste glass [5-7] and extra. The research showed that the alternative material can improve and suitable to used with appropriate amount in pavement. However, the researcher started to explore the using palm oil fuel ash (POFA) in asphalt pavement. Kamaluddin [8] conducted a research using POFA as filler material in stone mastic asphalt. The application of POFA enhanced the stability, stiffness and tensile strength. Borhan [9] also pointed out that the asphalt mixtures containing POFA is more resistance to permanent deformation compared to control.

This study discussed about the ability of palm oil fuel ash (POFA) used as filler in asphalt pavement. Samples were prepared and compacted according to Marshall Method. A few amount of POFA (3, 5, 7, 10%) were tested and compared to the sample without POFA, refer as control. The optimum POFA content for mix design ACW20 is determined and then tested with Marshall stability and resilient modulus.

The rest of this paper is organized as follows: The next sections discussed about the material and methods used for this study. Section 3 shows the results of performance test such as Marshall Stability test, Resilient modulus and finally the section 4 is the conclusion.

## 2.0 MATERIALS AND METHODS

The experiment design detailed in this study included one type of aggregate, one penetration grade of binder (PEN 80/100) and two types of filler (POFA and Ordinary Portland Cement-OPC). Quality testing for aggregate, bitumen and POFA was prepared. Aggregate design was in accordance with JKR/SPJ/1988 by Public Works Department (PWD) as shown in table 1. Meanwhile, the specific gravity for each material shows as table 2. It was occupied aggregate in 20mm sizing, 10 mm, quarry dust, cement and palm-oil fuel ash (POFA). The compaction method is Marshall with 75 blows for top and bottom sample. The value gained is reused for try and error method to obtain specification consider of sample to other tests. POFA was obtained from palm oil factories. The physical and chemical properties of POFA and OPC are shown in Table 2.

**Table 1**: Gradation Limits for ACW20 [10]

| Sieve Size, mm | Specification |
|---|---|
| 28 | 100 |
| 20 | 76-100 |
| 14 | 64-89 |
| 10 | 56-81 |
| 5 | 46-71 |
| 3.35 | 32-58 |
| 1.18 | 20-42 |
| 0.425 | 12-28 |
| 0.150 | 6-16 |
| 0.075 | 4-8 |

**Table 2:** The Specific Gravity Value for Each Material

| Material | Specific Gravity |
|---|---|
| Aggregate 20 mm | 2.726 |
| Aggregate 10 mm | 2.545 |
| Quarry Dust | 2.568 |
| OPC | 3.280 |
| POFA | 2.220 |
| Bitumen | 1.010 |

**Table 3:** Physical Property and Chemical Comparison Between Among OPC (Ordinary Portland Cement) and POFA [11]

| TESTS | OPC | POFA |
|---|---|---|
| **Physical Properties** | | |
| Fineness-Sp. Surface Area ($m^2$/kg) | 314 | 519 |
| Soundness-Le Chatelier Method (mm) | 1 | 1 |
| Specific Gravity | 3.28 | 2.22 |
| **Chemical Analysis (%)** | | |
| Silicon Dioxide ($SiO_2$) | 20.20 | 43.60 |
| Aluminium Dioxide ($Al_2O_3$) | 5.70 | 11.40 |
| Ferric Oxide ($Fe_2O_3$) | 3.00 | 4.70 |
| Calcium Oxide (CaO) | 62.50 | 8.40 |
| Magnesium Oxide (MgO) | 2.60 | 4.80 |
| Sulphur Trioxide ($SO_3$) | 1.80 | 2.80 |
| Sodium Oxide ($Na_2O_3$) | 0.16 | 0.39 |
| Potassium Oxide ($K_2O$) | 0.87 | 3.50 |
| Loss in Ignition(LOI) | 2.70 | 18.00 |

Laboratory studies were done and obtained POFA's size is finer than ordinary Portland cement and have a specific gravity value, 2.22. The optimum asphalt content (OAC) was determined using Marshall Stability Test which cover density, void filled with bitumen (VFB), stability and void total mixture (VTM) according to ASTM D1559. Marshall stability is the maximum load the material that can be withstand when tested in Marshall apparatus. The test is performed at a deformation rate of 51 mm/min and temperature of 60°C. Meanwhile, the Marshall flow is the deformation of specimen when the load starts to decrease [13]. This OAC was used to produce the sample for testing and integrated with optimum content of POFA with desired 4% air voids. The OAC obtained as 5.1% of total weight of mixture. Then, these values were verified with the specification provided by PWD whether they comply within the limit. Henceforth, the trial mixture prepared using the obtained OAC, 5.1%±0.5 and mixes with different percentage of POFA (3, 5, 7 and 10%) as filler to determine the maximum POFA in ACW20 design mixture.

## 3.0 Results and Discussion

### 3.1 Marshall’s Test

Marshall's test is carried out to determine optimum bitumen content in ACW20 design. It also could determine the maximum content level of POFA as filler in asphalt pavement. Those values acquired were calculated according to equations provided and compared with specification. In determining the optimum asphalt content, 15 samples were fabricated and then the six graphs have been plot via density, Voids Total Mix (VTM), Void Filled with Bitumen (VFB), Flow, Stability and Stiffness. However, only four graphs used for determination of optimum bitumen through density graph, VFB, Stability and VTM. The values for each parameter are within the specification limit, thus the OAC value was accepted. The process then determined the maximum POFA in ACW20 content using 5.1%±0.5 of bitumen content and tested with Marshall. The results are presented in Table 4.

**Table 4**: Marshall Result for different content of POFA

| Parameter | Specification | Bitumen Content, % | POFA Content, % | | | | |
|---|---|---|---|---|---|---|---|
| | | | 0 | 3 | 5 | 7 | 10 |
| FLOW | > 2.0 mm | 4.6 | 3.58 | 2.82 | 2.72 | 1.00 | 1.28 |
| | | 5.1 | 4.29 | 2.96 | 2.72 | 0.69 | 3.06 |
| | | 5.6 | 5.33 | 3.72 | 2.39 | 0.68 | 1.55 |
| STABILITY | >500 kg | 4.6 | 1522.99 | 1875.86 | 1838.47 | 1790.01 | 1767.76 |
| | | 5.1 | 1756.89 | 1599.41 | 1426.28 | 1393.94 | 1393.94 |
| | | 5.6 | 1652.64 | 1822.78 | 1082.44 | 1058.17 | 1027.84 |
| STIFFNESS | >250 kg/mm | 4.6 | 425.72 | 757.40 | 943.54 | 1907.26 | 1387.52 |
| | | 5.1 | 409.74 | 759.67 | 794.52 | 1511.97 | 722.43 |
| | | 5.6 | 310.29 | 790.51 | 670.76 | 1588.76 | 660.30 |
| VTM | 3 – 5% | 4.6 | 7.20 | 2.61 | 1.12 | 1.65 | 0.85 |
| | | 5.1 | 4.34 | 1.85 | 0.20 | 0.53 | 1.00 |
| | | 5.6 | 3.72 | 1.64 | 0.38 | 0.01 | 0.13 |
| VFB | 75 - 85% | 4.6 | 62.11 | 81.10 | 91.61 | 87.75 | 91.57 |
| | | 5.1 | 76.12 | 86.16 | 98.44 | 95.95 | 93.05 |
| | | 5.6 | 82.48 | 88.33 | 96.37 | 98.97 | 98.60 |

Table 4 shows the result of few parameters for different content of bitumen and POFA. The flow value is decreased when the content of POFA is increased. 7% and 10% of POFA shows the value exceeding the specification. In contrast, the stability and stiffness for all bitumen content and POFA is fulfilling the requirement. The important value here is the stability. The results show some of the inconsistency data with respect to the POFA contents. Refer to the OAC, the stability for 0% POFA have the highest Marshall stability values followed by 3, 5, 7 and 10% POFA, respectively. Borhan [9] also reported the stability of asphalt mixture is decreased with the increasing of POFA. Meanwhile, the VTM shows the inconsistent data especially for the higher content of POFA. The trend of VTM should be decreased as the increasing of POFA occupied the void in mixture. VFB also shows the value for POFA of 5% till 10% is out of the range. Therefore, the content of maximum POFA was defined and it was concentrating on only 3% either by using 4.6% or 5.1% bitumen content, which is shows a stated mixture that fulfill the JKR/SPJ/1988. This indicates the value of bitumen can be used in those range, while POFA's content also must be in ≤ 3%. When POFA's content is increase, the sample will no longer fulfill the specification. The specific gravity also shows that the increasing percentage of POFA, the decrease of specific gravity. The lower specific gravity value is generally indicated the weak or absorptive material [12]. The excessive amount of POFA can lead to the deleterious materials and reduced the strength of sample. The results clearly depicts in Table 5.

**Table 5**: Specific Gravity of different POFA content

| Material | Mixed (%) | | | | |
|---|---|---|---|---|---|
| POFA | 0 | 3 | 5 | 7 | 10 |
| Aggregate 20mm | 37 | 37 | 37 | 37 | 37 |
| Aggregate 10mm | 13 | 13 | 13 | 13 | 13 |
| Quarry Dust | 40 | 40 | 40 | 40 | 40 |
| OPC | 10 | 7 | 5 | 3 | 0 |
| Total | 100 | 100 | 100 | 100 | 100 |
| $SG_{mix}$ | 2.672 | 2.616 | 2.579 | 2.542 | 2.490 |

### 3.2 Resilient Modulus Test

The structural response of asphalt mixture needs the modulus evaluation. Sample is measured with suitable parameters, and tested by using Universal Testing Machine (UTM) equipment as shown in Figure 1 in the indirect tensile mode accordance with ASTM D 4123 [13]. Resilient modulus is non-destructive test, therefore the sample were subjected to this test before conducting Marshall stability test. The load is commonly applied with a duration of 0.1 second and a rest period of 0.9 seconds. The figure 2 shows the result of resilient modulus for each percent of POFA at the temperature 25°C. Three samples fabricated for each POFA contents. According to the result, specimen incorporating 4.6% bitumen with 3% POFA had higher modulus with value 4260 Mpa. Refer to the graph, there was non-uniformity pattern especially for bitumen content 4.6% WITH POFA content 3%. Therefore, this value needs to be ignored. As stated by IKRAM, the best Resilient Modulus (MR) is in previous range. For this study, value of 5.1% bitumen which is combined with ≤ 5% POFA that have more position in a range of 2000-3000 Mpa compared to other percent of POFA. However, during Marshall test, VFB parameter for 5.1% bitumen incorporating 5% POFA did not comply with the specification. Thereby, the consideration is then made to the sample with 5.1% bitumen incorporating 3% POFA.

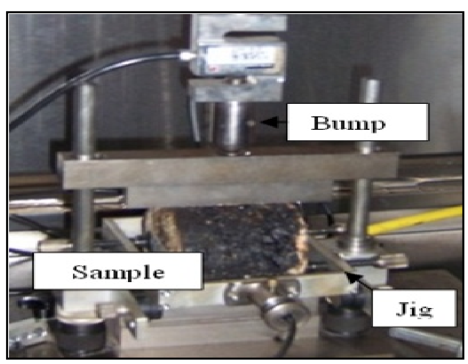


**Figure 1** : Resilient Modulus Equipment

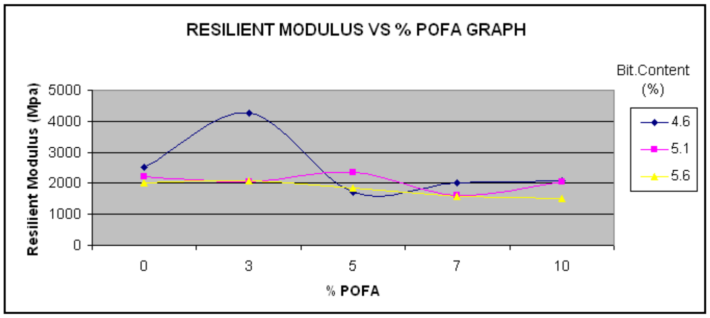


**Figure 2** : Graph of Resilient Modulus Graph vs Percent of POFA

## 4.0 CONCLUSION AND RECOMMENDATION

According to the result, the addition of POFA improves the stability of asphalt mixes. However, it needs the proper evaluation in order to determine the effective amount of POFA incorporating to the optimum bitumen content for a design mix. In Marshall stability test, the value for asphalt mixes with POFA were found generally higher than the control mixture. This indicates the addition of POFA in appropriate amount was helping in improving the stability of asphalt mixture. Meanwhile, for resilient modulus test, obtained that the most suitable content of bitumen value is in inclusion of 4.6% to 5.1% combined with ≤3% POFA, it shows that ACW20 designed can apply POFA as filler in particular percentage rate. Even though its only suitable use as alternatives filler in particular value, at least it able to help minimize the disposal palm oil fuel ash and add more interest diversity from crop of palm oil in our country. Further study is needed to validate the research finding herein with various gradation and bitumen types. Other testing can be apply are creep test and wheel tracking test or used other reliable method like Superpave.

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