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Research paper

Modification of HMA using palm oil boiler ash as a filler

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Abstract

Waste material disposal has become a major factor in affecting the environmental condition. Palm Oil Boiler Ash (POBA) is known as one of the palm waste. In this study, a determination has been done in order to investigate the effect of POBA on the ACW 14 mix when it is added as a filler. Two different type of samples were prepared which were control sample and POBA modified samples. Control sample was prepared by using 4% of quarry dust and 2% of Ordinary Portland Cement (OPC). The POBA used in this study was sieved through the 0.075 mm sieve to obtain the portion of POBA that can be added as a filler. Inclusion of POBA was done using dry method which is by adding it together with aggregates instead of bitumen. The percentage of POBA added into the mix varied from 25% to 100% by the weight of the filler content. The Marshall Method was used to prepare both control and modified samples. Marshall stability and flow test were conducted on these samples in order to determine the strength of the mix. The results were compared between control and modified samples to determine the effect of POBA on the ACW 14 mix. From the comparison, control sample gave better results compared to the modified samples. As a conclusion, POBA affected the mixture negatively.

Keywords: *Palm Oil Boiler Ash (POBA); Filler; Asphalt Concrete Wearing (ACW); Stability; Flow.*

1. Introduction

Transportation system is very essential to provide fast and elementary ways to travel or move from one place to another. There are different modes of transport such as air, water and land. Air transportation is one of the most convenient method when long distances are travelled. However, sometimes it can be useful for short distances too especially when time acts as a factor. Water transportation will be referring to the movement of watercrafts over water bodies. Land transportation is referring to the movement of vehicles, animals, humans and goods from one place to another on land. Land transportation can be classified into two different category such as rail transportation and road transportation.
In Malaysia, road transportation has been the most essential and utilized mode of transport. Road is made up of a composite material known as asphaltic concrete. There are many types of asphaltic concrete, however, in this study the investigation is going to cover majorly on hot-mix asphalt (HMA). HMA consists of aggregates, mineral filler and asphalt.
Mineral fillers are materials, which are added into the mix to alter the properties of the HMA mix. Fillers will be used to fill up the voids between the aggregates and to reduce the voids present in the mixtures. There are many types of fillers such as hydrated lime, Ordinary Portland Cement (OPC), quarry dust and any fine materials, which can pass through the 0.075mm sieve.
Malaysia is very well known for being the world's largest production of palm oil. Palm Oil Fuel Ash (POFA) and Palm Oil Boiler Ash (POBA) are the two-major solid waste from the palm oil mill industries. POFA is the by product from power electricity generation plants that used palm oil shells and palm oil bunches as burn materials. Meanwhile boiler ash is the biomass known as mesocarp fiber and shell that consists of clinkers and ash that has been burnt in the boiler.
Besides that, the increment in the number of vehicles traveling on the road eventually increases the traffic loading. These increments cause failure and deformations on the pavements. Even though the pavements are designed to last longer, however the repeated application of the traffic load causes the road surface or pavements to fail by having cracks on the surface, surface deformation; e.g. rutting, which creates channels in the wheel path and also potholes which are created by the presence of water in the underlying soil that weakens the soil and causes it to disintegrate due to the repeated traffic loadings.

2. Materials

The materials used in this study were bitumen, coarse aggregates, fine aggregates, filler, cement and POBA.

2.1. Aggregates

The aggregate was supplied by Hanson Quarry which is located at Cheras, Kuala Lumpur, Malaysia. When the aggregate was taken from the quarry, it was wet due to the rain. Therefore, drying the aggregate was the major priority because the presence of water in the aggregates can manipulate the test results. The aggregate was dried in the oven for 24 hours at the temperature of 120ºC. Design gradation for the mixture used in this study was gradation that meets the ACW14 specification as mentioned in JKR specification.

2.2. Bitumen

Bitumen with a grade of 80/100 was used for all ACW 14 mixtures (control and modified samples) as stated in JKR specification. Since bitumen acts as a binding agent in the HMA mix, certain tests has been conducted in order to find the characteristics of the bitumen.

2.3. Palm oil boiler ash (POBA) [1]

The kernels, nutshell and fibers from the palm oil production waste were burnt in the boilers to generate steam to run a turbine to generate electricity. When these wastes were incinerated, the waste from the burning process known as boiler ash was obtained at the lower compartment of the boiler. POBA used in this study was taken from factory in Jengka, Pahang. POBA was sieved through 75µm sieve size to ensure that it satisfied ASTM filler material definition of 70%- 100% passing 75µm sieve.

3. Methodology

3.1. Bitumen test

3.1.1. Penetration test [2]

Penetration test helps to identify the consistency of the bitumen. Consistency of the bitumen defines as the fluidity level of the bitumen at any certain temperatures. Bitumen is a thermoplastic material. Therefore, the consistency of the bitumen differs with the temperature. The consistency of the bitumen will be determined by allowing a standard needle to penetrate vertically on the sample for 5 seconds. The depth of penetration is known as the penetration value. The temperature will be maintained at 25 °C throughout the test.

3.1.2. Softening point test [3]

Bitumen is unlike any other substances because it does not have a specific melting point. When the temperature rises, the bitumen changes from thick and viscous material to a softer and less viscous liquid. The determination of the bitumen's softening point is important. From this experiment, ring-ball apparatus was used in order to determine the softening point of the bitumen.

3.1.3. Ductility test [4]

Bitumen has a tendency to elongate and have a high elasticity. Therefore, ductility property of the bitumen helps the road surface to elongate under traffic load without getting crack. This test determines the ductility of the bitumen which is measured by the elongated distance before the bitumen breaks off into two pieces.

Table 1: Standards for Bitumen Tests

Test	Standard
Softening Point test	ASTM D36/D36M – 09
Penetration Test	ASTM D5 -06
Ductility Test	ASTM D113-07

3.2. Aggregate test

3.2.1. Aggregate impact value test [5]

The main objective of this experiment is to determine the toughness of the aggregates which were used for the preparation of Marshall samples. This test also helps to identify the aggregates suitability in resisting sudden shock or impacts that acts on the road due to heavy traffic. The aggregate specimen was subjected to 15 blows of standard hammer. The percentage loss of weight of aggregates which passes through the 2.36mm sieve is the impact value of the aggregates.

3.2.2. Aggregate shape test [6]

The percentage of flaky and elongated aggregates was used to determine the shape of the aggregates. For road construction, flaky and elongated aggregates will not be used due to its effect which can weaken the pavement strength. Regular shaped aggregates are the most desirable aggregates that will be used for road constructions. This is because regular aggregates have irregular surface which helps to provide a better interlocking among the aggregate.

3.2.3. Specific gravity test [7]

Specific gravity of aggregate is known as the ratio obtained by comparing the density or weight of a given volume of aggregates with density of water with the same volume as the aggregate in a specific temperature. At the room temperature, the specific gravity of water will be 1. One of the main importance of determine the specific gravity of aggregate will be to identify the tendency of the aggregate to absorb water. Besides that, it also determines whether the aggregates have any possibilities of getting contaminated by impurities. Therefore, determination of specific gravity can be helpful to remove the impurities from the aggregates. For this study, the specific gravity was determined to assist in the calculation of volumetric properties which are void in mineral aggregate (VMA) and voids filled with bitumen (VFB). Through this test, it will be helpful in order to understand the relationship between the absorption rate of aggregates and the amount of bitumen that will fill the voids in the aggregates. This relationship has the tendency to affect the durability of the asphalt concrete.

Table 2: Standards for Aggregate Test

Test		Standard
Aggregate Impact Value		BS 812 Part 112-1990
Aggregate Shape Test		BS 812: Part 105-1989
Specific Gravity	Coarse Aggregates	ASTM D7370
	Fine Aggregates	
	Loose Mix	ASTM D6857

3.2. Preparation of marshal sample [8]

Control samples were prepared for the bitumen content which varies from 4% to 6% with an increment of 0.5%. Three Marshall samples were prepared for each bitumen content. This was done in order to get more precise and accurate result. The Marshall samples were prepared by referring to the ASTM D6926 – 16. Then, the bulk density of the samples was determined by referring to ASTM D 2726 – 04. After that, Optimum Bitumen Content (OBC) for the control sample were determined. Once the OBC was determined, validation test was done on the Marshall samples that were prepared by using the OBC.

Modified samples were prepared by using the OBC which was determined for the control samples. For this study, Palm Oil Boiler Ash (POBA) was used in a powder form. Since it was used as a filler modifier, the size of POBA powder has to pass through 0.075mm sieve. Four different percentage of POBA configurations were used for this study which were (25%, 50%, 75%, 100%) of the total weight of the filler. Once the modified samples were prepared, the following procedures were same as the procedures that has been conducted for control samples. Lastly, the Optimum POBA Content was determined by choosing the percentage of POBA added as the filler which gives the best results compared to other configurations.

Table 3 and 4 show the configurations used for both control and modified samples respectively.

Table 3: Details of Mixes Produced for Control Sample

Bitumen content (%)	Aggregates (%)	Quarry dust (%)	OPC (%)
4	96	4	2
4.5	95.5	4	2
5	95	4	2
5.5	94.5	4	2
6	94	4	2
5.15 (OBC)	94.85	4	2

Table 4: Details of Mixes Produced For Modified Sample

Bitumen content (%)	Aggregates (%)	POBA (%)	Quarry Dust (%)	OPC (%)
5.15	94.85	4 (100%)	0	2
5.15	94.85	3 (75%)	1	2
5.15	94.85	2 (50%)	2	2
5.15	94.85	1 (25%)	3	2

The gradation limit of the aggregate used in Marshall mix design was in accordance with JKR/SPJ/2008-S4 [8]. The gradation limit of the aggregate is as shown in Table 5.

Table 5: Gradation Limit of Aggregate

Mix Type	Wearing Course	Design Gradation (Percentage Passing by Weight)
Mix Designation	AC 14	
BS Sieve Size (mm)	Percentage Passing by Weight	
20.0	100	100
14.0	90 – 100	95
10.0	76 – 86	81
5.0	50 – 62	56
3.35	40 – 54	47
1.18	18 – 34	26
0.425	12 – 24	18
0.150	6 – 14	10
0.075	4 – 8	6

Marshall Samples were prepared in accordance with the steps as follow [8]:

1) Aggregate evaluation.
2) Preparation of Marshall samples.
3) Bulk and maximum specific gravity determination.
4) Marshall Stability and flow test.
5) Plotting test results and determination of optimum bitumen content (OBC).

Fig. 1: POBA Modified Marshall Samples.

3.3. Marshall stability and flow test [8]

Marshall Stability and Flow tests were carried out in order to find the optimum bitumen content (OBC) of the mixes. The Marshall Mix design procedure currently used in Malaysia for asphalt concrete mix design to determine the optimum bitumen content was adopted. Table 6 shows the requirement specified in the JKR/SPJ/2008 for ACW 14 mix.

Table 6: JKR Requirements for ACW 14 Mix [8]

Parameters	Wearing Course
Stability, S	>800 kg
Flow, F	2.0 – 4.0
Stiffness, S/F	>200 kg/mm
VTM	3.0 – 5.0%
VFA	70 – 80%

4. Result and discussion

4.1. Bitumen test

Table 7 shows the results obtained from the bitumen tests.

Table 7: Average Results for Bitumen Test

Test	Average Result
Softening Point	50.5 °C
Ductility	>140 cm
Penetration	81.34 d-mm

4.2. Aggregate test

Table 8 shows the average results obtained from the aggregate evaluation test.

Table 8: Average Results for Aggregate Test

Test		Average Result
Aggregate Impact Value		43 %
Aggregate Shape Test	Flakiness	10.28 %
	Elongation	17.14 %
Specific Gravity Test	Fine Aggregate	2.649
	Coarse Aggregate	2.636

4.3. Optimum bitumen content (OBC)

A 4-6 % asphalt content range was used to determine the optimum bitumen content for the mixes considered in this study. Table 9 shows the results obtained for the control samples. Parameters used to determine the OBC are Stability, Density, VTM and VFB which is in accordance with JKR 2008 ACW 14 for wearing coarse recommendations.

Table 9: Average Results for Control Sample.

Volumetric and Strength Properties	4%	4.5%	5%	5.5%	6%
Density	2.278	2.296	2.335	2.356	2.352
Stability (kg)	731	806.25	686.95	739	510.75
Flow (mm)	4.85	4.55	5.00	4.70	4.90
Stiffness (kg/mm)	150.72	177.2	137.39	157.23	104.23
VTM (%)	8.019	6.605	4.333	2.745	2.235
VFB (%)	52.450	60.294	72.341	82.093	85.976

The Optimum Bitumen Content was determined as specified in the JKR specifications which are [8]:

i) Peak of curve taken from the stability graph.
ii) Peak of curve taken from the bulk specific gravity graph.
iii) VFB equals to 75 % for wearing course and 70 % for binder course from VFB graph.
iv) VTM equals to 4.0 % for wearing course and 5.0 % for binder course from the VTM graph.

The OBC calculated for the control sample was 5.15 %. Table 10 show the result of validation test for control sample at OBC.

Table 10: Average Results Obtained for OBC.

Volumetric and Strength Properties	5.15 % (OBC)
Stability (kg)	809.1
Flow (mm)	4.3
Stiffness (kg/mm)	188.16
VTM (%)	4.177
VFB (%)	73.637

4.4. Optimum POBA content

A range from 25% to 100% of POBA content were used in this study. Table 11 shows the results obtained for the modified samples.

Table 11: Average results for Modified Samples

Volumetric and Strength Properties	25% POBA	50% POBA	75% POBA	100% POBA
Density	2.321	2.324	2.305	2.290
Stability (kg)	581.25	604.5	632.4	538.45
Flow (mm)	4.05	4.50	4.75	4.25
Stiffness (kg/mm)	143.52	134.33	133.14	126.69
VTM (%)	4.675	4.574	5.357	5.965
VFB (%)	71.288	71.756	68.266	65.748

Since there were four different configurations of POBA content were used in this study, therefore the optimum POBA content has to be determined to know which POBA content gave the best results. Only two parameters have met the JKR requirements which were VTM and VFB. Other than these two parameters, none of the results met the JKR requirements. However, from the results obtained it is possible to find out the optimum POBA content by analysing each POBA configurations. The 25% POBA content has given the best results for flow, stiffness, VTM and VFB when it was compared with other configurations. Therefore, 25% of POBA content will be the optimum POBA content for the modified Marshall samples.

4.5. Marshall stability and flow test

Both OBC and optimum POBA content samples were compared in order to understand the effect of POBA to the ACW 14 mix. Table 12 shows the comparison between modified and control sample.

Table 12: Comparison of POBA Modified and Control sample

Volumetric and Strength Properties	Control Sample (5.15% Bitumen Content)	POBA Modified Sample (25% POBA Content)	JKR (2008)
Stability (kg)	809.1	581.25	> 800
Flow (mm)	4.3	4.05	2.0 – 4.0
Stiffness (kg/mm)	188.16	143.52	> 200
VTM (%)	4.177	4.675	3.0 – 5.0
VFB (%)	73.637	71.288	70 - 80

From the strength properties point of view, control samples gave a better stability value which was 809.1 kg compared to the POBA modified samples which has a stability value of 581.25 kg. For flow, POBA modified samples gave a better flow value which was 4.05 mm compared to the flow value of control sample which was 4.3 mm. Both the samples exhibited flow values which did not satisfied the JKR specification. However, it is believed that the difference between the flow value obtained and the flow value needed by JKR is considerably small. Therefore, the small difference in flow still can be accepted. From the results obtained for stiffness, it is noticeable that control sample provided a higher stiffness value which was 188.16 kg/mm compared to the POBA modified sample which had a stiffness value of 143.52 kg/mm.

From volumetric properties point of view, both control and POBA modified sample gave a result which satisfied the JKR requirement. However, it was possible to notice that inclusion of POBA increased the VTM value of the HMA compared to the control sample. Besides that, the VFB experienced a reduction when POBA was added into the HMA sample.

When both the results were compared with the JKR/SPJ/2008 requirements, it is noticeable that control sample has more parameters which met the requirements compared with the modified sample. Therefore, POBA provides adverse effects on the HMA mix when it is added into the mix as filler.

5. Conclusion

Palm Oil Boiler Ash was added in the HMA as filler in order to determine the possibilities of using waste materials in the pavement production. From the results obtained, the following conclusions have been determined:

i) The OBC for the control sample is 5.15 %.
ii) The strength properties, which are stability and stiffness, experienced a reduction while flow experienced a positive impact for POBA modified sample.
iii) Inclusion of POBA as a filler into the mix has a slight effect on the volumetric properties, however, it is still in the range specified by the JKR, therefore, it is considered as an insignificant effect.

Overall, POBA can be considered as unsuitable material to be utilized as a filler replacement in HMA.

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