



## Effect Of Oil Palm Mesocarp Fibre Ash (Opmfa) On The Strength Properties Of Hot Mix Asphalt

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### ABSTRACT

*This study experimentally investigates the effects of using oil palm Oil palm mesocarp fibre ash (OPMFA) as replacement for common filler in Hot Mix Asphalt (HMA) production. Marshall Mix design methods was adopted for sample preparation and testing. To obtain the optimum binder content (OBC), fifteen (15) compacted samples were prepared for strength and volumetric properties testing at varying bitumen contents of 4.5%, 5.0%, 5.5%, 6.0% and 6.5%, in accordance with Nigeria General Specification for Road and Bridges. An OBC of 5.5% was obtained and used for the design of mixtures with different OPMFA contents (5, 10, 15, 20, 25 and 30%). Experimental results indicated that the stability and flow value with the OBC for the mixture having 5% OPMFA content satisfied the standard specification of Nigeria General Specification for Road and Bridges. Thus, a replacement of the conventional filler with OPMFA upto 5% is recommended for incorporation into Hot Mix Asphalt (HMA).*

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### INTRODUCTION

Hot Mix Asphalt (HMA) mostly used for road construction in tropical countries like Nigeria is a combination of approximately 95% stone, sand, or gravel that is bound together by bitumen. It is a continuously graded mixture that forms an interlocking structure to meet strength and durability requirements (Nicholls, 2004).

One of the major problems attributed to the use of HMA in road construction is the high cost and decreasing supply of raw materials of its constituent materials especially cement. Cement is not only expensive in terms of cost but also, its production process has serious detrimental effects on the environment. It has been reported that the process of cement production contributes up to 7% of the CO<sub>2</sub> emission to the atmosphere and this causes

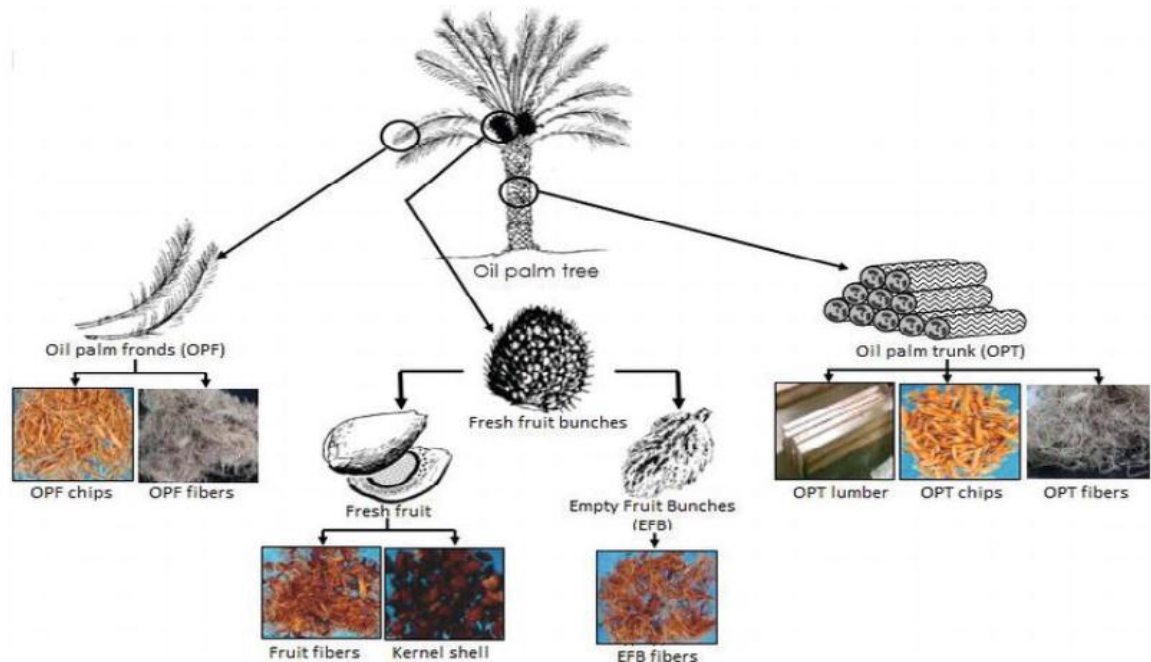
global warming effect that have greatly plagued the environment (Shuaibu et al., 2019; Kaura et al, 2016).

The considerable effort to reduce the global warming effect on the environment by reducing CO<sub>2</sub> emission, improve waste management, and reduce dependency expensive cement for HMA production, has necessitated the development of new paving materials from sustainable sources such as oil palm.

Oil palm mesocarp fibre (OPMF) is the biomass residue obtained after pressing the palm fruits for palm oil extraction. Approximately 10% palm oil and palm kernel oil is obtained from palm oil extraction process while the remaining 90% is left as waste or biomass not used by the industry (Dungari et al., 2018, Riansa-ngawong and Prasertsan, 2010). Globally oil palm biomass

is produced and utilized in million metric tonnes annually with expected waste of 295 million tonnes. Generally, oil palm waste such as pressed fruit fibre (PFF), empty fruit bunches (EFB), oil palm trunk, oil palm shell

(OPS), and oil palm ash (OPA), oil palm trunk (OPT) and oil palm fronds (OPF) are good source of biomaterials (Dungari et al., 2018). Figure 1 below shiw the oil palm waste and its derivatives.



**Figure 1:** Oil palm waste forms and its derivatives (Dungari et al., 2018).

Currently, these waste are mainly utilized as fuel for steam boilers at the mills or left as waste (Abdul Hamid et al., 2010; Nordin et al., 2013) and this has caused serious environmental pollution. Thus, there is a need to explore a more useful and sustainable way to utilize the waste since it is available in large quantities in Nigeria.

It is important to mention at this point that a wide variety of waste materials with pozzolanic properties in either their natural or processed forms generated via industrial and agricultural activities of man have been generally investigated for partial or complete replacement of cement as fillers in Hot Mix Asphalt production. Some materials investigated for possible incorporation into HMA include; palm oil

waste ash, rice husk ash, palm kernel shell ash, periwinkle shell ash, kaolin, metakaolin, corncob ash, millet husk ash, coal bottom ash, slag, fly ash and blast furnace slag (Murana et al., 2014; Sadeeq et al., 2014; Murana and Sani, 2015; Oluwaiwo and Owolabi, 2015; Nwaobaka and Agunwamba, 2014; Mistry and Roy, 2016; Suji et al., 2016; Abu Salem et al., 2017).

Currently, there are scarce studies in the utilization of Oil palm mesocarp fibre ash (OPMFA) in the production of hot mix asphalt in Nigeria, though it has been reported to have good pozzolanic properties necessary for the replacement of cement in HMA.

In the present study, Oil palm mesocarp fibre ash (OPMFA), was used to



partially replace cement filler in HMA designed for use in wearing surfaces.

The above aim was achieved through the following objectives:

1. To perform physical properties tests on mineral aggregates to ascertain their suitability for use in HMA production.
2. To obtain the oxide composition of Oil palm mesocarp fibre ash (OPMFA) using x-ray fluorescence (XRF) and classify it based on ASTM C618, (2003) classification of pozzolanas.
3. To determine the optimum binder content (OBC) for asphalt concrete production and finally
4. Find out the effect of adding the different percentage of Oil palm mesocarp fibre ash (OPMFA) on the stability-flow properties of HMA to be used in highway wearing course.

The finding of this study is cardinal in finding a sustainable solution to the huge amount of oil palm based waste lying on the oil palm mill, reduction in demand for cement, and ultimately enhancing cost-effective production of HMA for road infrastructure construction.

## MATERIALS AND METHODS

### Materials

Materials used for the study are as follows;

- bitumen
- coarse aggregate and fine aggregate
- mineral filler (Oil palm mesocarp fibre ash OPMFA and cement)

The coarse and fine aggregates were obtained from Nagarta local quarry, Sokoto Road, Zaria, Kaduna State, Nigeria. The fine aggregate used is a clean river. The Ordinary Portland Cement is Dangote 3X brand which obtained from Samaru open

market in Zaria, Kaduna State. The bitumen used was obtained from the Nigeria National Petroleum Cooperation (NNPC) in Kaduna State. Empty palm fruit bunch which is the source of the Oil palm mesocarp fibre ash (MFS) was obtained from Abeokuta, Ogun State.

### Methods

To ascertain the suitability of bitumen, fine and coarse aggregates, and filler for HMA mixtures, physical properties test was conducted on each constituent materials in the Department of Civil Engineering, Ahmadu Bello University, Zaria. Furthermore, the chemical composition of OPMFA was conducted to determine its oxide composition. The following section discusses the test on constituent materials and code of practice used in testing these materials.

#### Test on coarse aggregates

Test conducted on the coarse aggregates is (Aggregate impact value/hardness test (BS 812 PART 111), Aggregate crushing value (BS 812 PART 112), Aggregate specific gravity (ASTM, C127), Size and gradation (BS 812-103.2).

#### Test on fine aggregates

The tests conducted on the fine aggregates are specific gravity (ASTM 128), sieve analysis (BS 812-103.2) analysis, and water absorption (BS 812 Part 3).

#### Test on Mineral aggregate (cement and MFA)

Experimental test on cement are; Initial and final setting time (BS EN 196 part 3), Soundness test (BS EN 196 part 3), and specific gravity (ASTM C188).

To obtain the Oil palm mesocarp fibre ash, the empty fruit bunch was first washed and dried before calcining in University of Abeokuta facility furnace at a temperature



of 600°C for 2 hours to obtain amorphous material. Test on MFA is; specific density (ASTM D854) and X-ray Fluorescence (XRF) to determine the oxide composition. X-ray Fluorescence (XRF) on MFA was conducted in the Chemistry Department, Ahmadu Bello University, Zaria using energy dispersive spectrometer designed for detection and measurement of elements in a sample. The analysis was carried out according to (ASTM C618).

#### *Test on Bitumen*

Tests on bitumen are Penetration test (ASTM D5), Solubility test (ASTM D4), Viscosity test (ASTM D2170), Ductility test (ASTM D113), Flash and fire point test (ASTM D92), Specific gravity test (ASTM D70) and softening point (ASTM D36).

#### **Marshall Test experimental plan and specimen preparation**

Asphalt Institute (1994) recommendations were used to prepare specimens weighing 1200g, 101.5 mm diameter and 63.5 mm height compacted with 75 hammer blows on each side to simulate heavy traffic situation. The specimens are tested for bulk specific gravity in accordance with ASTM D1559 (2000). The specimens are kept immersed in water in a thermostatically controlled water bath at 60°C for 30 to 40 minutes and transferred within 30 seconds to the Marshall Test head where they are tested for Marshall Stability and flow in accordance with ASTM D1559 (2000). The volumetric test carried out are CDM, VMA, VIM and VFB. Theoretical Maximum Specific Gravity of the Mix (G<sub>mm</sub>) was determined using ASTM D 2041-95 and Bulk Specific Gravity or Compacted Density of the Mix (CDM) using ASTM D1188-96. ASTM D3203-94 was used to estimate Void

in the Mix (VIM). ASTM D1559 (2004) was used to determine the stability and flow of specimens.

To determine the optimum bitumen content, the relationships between binder content and the properties of mixtures such as stability, flow, bulk density, voids filled with bitumen (VFB), void in mineral aggregate (VMA) and void in mix (VIM) at no WFS replacement (control) were established. Three (3) specimens each were made for five bitumen content (4.5, 5.0, 5.5, 6.0 and 6.5%) in accordance with Asphalt Institute specifications, making a total of twelve (12) samples. The optimum binder content is selected as the average binder content for maximum density, maximum stability and specified percent air voids in the total mix.

## **RESULTS AND DISCUSSION**

### **Physical properties of Coarse aggregate**

Since the HMA is consisted majorly of aggregate, it is, therefore, necessary to measure the strength and toughness of the coarse aggregates as it has a significant bearing on the physical, mechanical and durability requirement of the HMA in service.

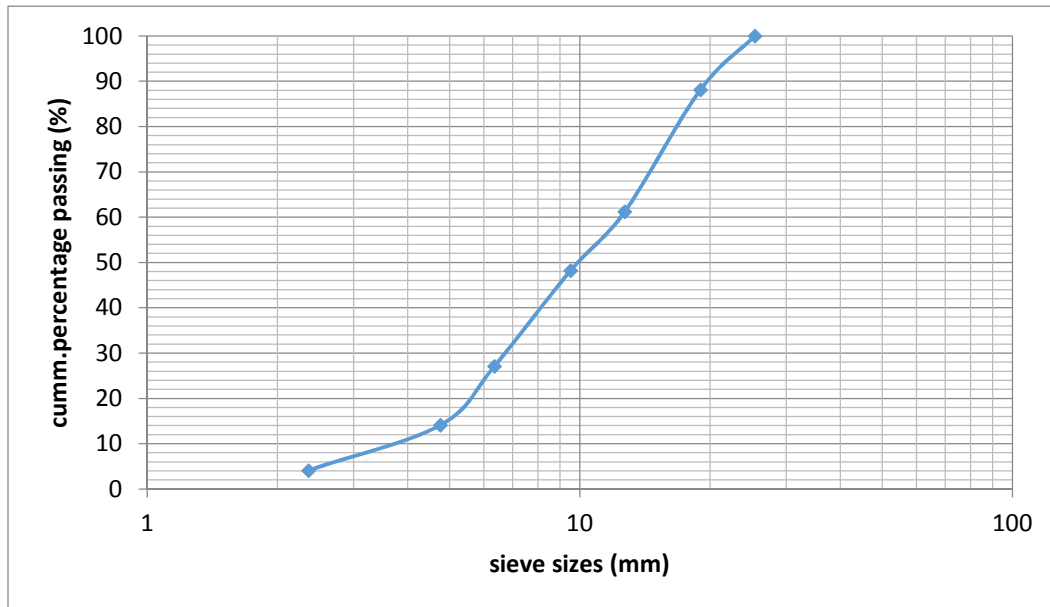
Table 1 shows the summary of the test conducted on coarse aggregates, the result obtained and limit of code specification. Figure 1 below shows the result of the sieve analysis.

From the test of physical properties results obtained, it can be observed that the aggregate meet codes specification, thus, adjudged suitable for use in HMA. The sieve analysis curve shown in figure 2 below shows that the aggregates are well-graded as they satisfy ASTM D3515 code limits, thus, suitable for the production of HMA.



**Table 1:** Physical Properties of Coarse Aggregate

Test conducted	Code used	Results	Code specification
Aggregate crushing value (%)	BS 812 part112	18.65	<30
Aggregate impact value (%)	BS 812 part111	18.87	<30
Specific gravity	ASTM C127	2.70	2.55-2.75
Water absorption (%)	BS 812 part 2	0.46	-



**Figure 2:** Sieve Analysis for Coarse Aggregate

**Physical Properties of Fine Aggregate**

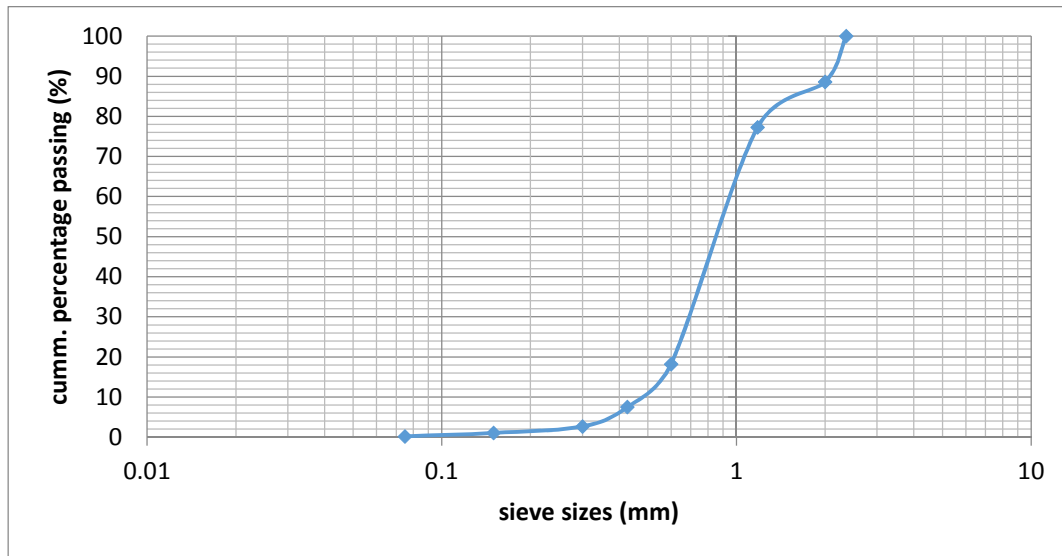
The test conducted on the fine aggregates is; specific gravity, sieve analysis, water absorption and the results alongside code specifications and limits are as shown in table 2 and figure 3 below. From the result

in table 2, it can be concluded that the fine aggregate is suitable for use in HMA production since it meets all the code specifications. Also, the sieve analysis results showed that the fine aggregate is well-graded, thus, adjudged suitably too.

**Table 2:** Physical Properties of Fine Aggregate

Test Conducted	Code Used	Test Result	Code Specification
Specific Gravity of Fine Aggregates	ASTM C128	2.63	2.55 – 2.75
Density of Fine Aggregates (lb/Ft <sup>2</sup> )	ASTM C127	164.15	> 160
Water Absorption For Fine Aggregate (%)	BS 812 Part 3	8.62	< 15
% Passing 0.075 mm Sieve	ASTM C116	0.20	< 5

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**Figure 3:** Sieve Analysis for Fine Aggregates

**Physical properties of Mineral Filler**

The physical properties test performed on cement revealed that the cement is ordinary Portland cement. The chemical composition using x-ray fluorescence test (XRF) and other physical properties on Oil palm mesocarp fibre ash (OPMFA) shows that it is a pozzolana of class N with a specific gravity value of 1.92.

The particle size distribution of cement and WFS showed similar grading curve, this implies that their sizes are similar and can be used together.

The physical and chemical properties test of the mineral fillers in accordance with standard specification are presented in tables 3 and 4 below.

**Table 3:** Physical Properties of Filler (cement and MFA)

Test	Code Used	Value	Code Limit
Initial Setting Time of cement (minute)	BS EN 196 PART 3	68	>45
Final Setting Time of cement (minute)	BS EN 196 PART 3	255	<375
Soundness of cement (mm)	BS EN 196 PART 3	3.0	<10
Specific Gravity of cement	ASTM C188	3.1	3.15
% of cement passing 0.075 mm sieve	ASTM C117	97	>90
Specific Gravity of Oil palm mesocarp fibre ash	ASTM D854	1.92	
% of Oil palm mesocarp fibre ash passing 0.075 mm sieve	ASTM C117	95	90
Pozzolana class	ASTM C618	N	N, F
Plasticity index (%)	ASTM D4318	0	< 4

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**Table 4:** Oxide Composition of Oil palm mesocarp fibre ash (OPMFA)

Component	Weight fraction (%)	Component	Weight fraction (%)	Component	Weight fraction (%)
SiO <sub>2</sub>	72.0	V <sub>2</sub> O <sub>5</sub>	0.01	Fe <sub>2</sub> O <sub>3</sub>	8.077
SO <sub>3</sub>	2.32	K <sub>2</sub> O	7.28	CuO	0.0977
Cl	1.13	TiO <sub>2</sub>	1.54	CaO	3.78
TiO <sub>2</sub>	0.900	Cr <sub>2</sub> O <sub>3</sub>	0.017	MnO	0.071
ZrO <sub>2</sub>	0.244	SrO	0.039	ZnO	0.184
Rb <sub>2</sub> O	0.046	Y <sub>2</sub> O <sub>3</sub>	0.010	RuO <sub>2</sub>	0.31
BaO	0.03	Eu <sub>2</sub> O <sub>3</sub>	0.17	CeO <sub>2</sub>	0.03

**Physical properties of bitumen**

Consistency, purity, safety and grading test was conducted in accordance with standard specification. The result of the test alongside code specifications is presented in Table 5 below.

The results obtained revealed that the bitumen is of 60-70 penetration grade. Also, the bitumen meets the safety and purity requirements to be used in HMA production.

**Table 5:** Preliminary test result and code limit on the bitumen.

Test conducted	ASTM Code	Test Result	Code specifications
Penetration at 25°C, 0.1mm	ASTM D5-97	64.7	60-70
Softening point (°C)	ASTM D36-95	48.5	46-56
Flash point (Cleveland open cup) °C	ASTM D92-02	248	Min.232
Fire point (Cleveland open cup) °C	ASTM D92-02	256	Min.232
Ductility at 25°C, cm	ASTM D113	116	Min.100
Specific gravity at 25°C, (g/cc)	ASTM D70	0.98	0.98-1.02
Solubility in trichloroethylene, %	ASTM D2042	99	Min.99

**Optimum Binder Content (OBC)**

To obtain the optimum binder content necessary for the asphalt paving mixture at different MFA replacements, The relationships between binder content and the properties of mixtures such as stability, flow, bulk density, voids filled with bitumen (VFB), void in mineral aggregate (VMA) and void in mix (VIM) at no replacement (control) was established. Fifteen (15) samples each weighing 1200 grams with diameter of 101.5mm diameter and 63.5mm height were prepared using five different bitumen

contents (4.5, 5.0, 5.5, 6.0 and 6.5%) as specified by Asphalt Institute, (1997), and ORN 19, (2003). Optimum bitumen content was calculated as an average of bitumen values that correspond to maximum stability, maximum bulk density and median of the air void. The results of the HMA mixtures at no MFA replacement (Figures 4-9) and that of typical compacted HMA as specified by Asphalt Institute and Nigerian General Specifications for Roads and Bridges (Table 6) is as presented as follows;

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**Table 6:** Properties of Compacted Asphalt Concrete Specimen (Nigerian Standard Specifications for Roads and Bridges).

Property	Base course	Wearing course
Optimum Binder Content	4.5% - 6.5%	5.0% - 8.0%
Stability (not less than)	3.5kN	3.5kN
Flow	2mm – 4mm	2mm – 4mm
V I M	3% - 8%	3% - 5%
VFB	65% - 72%	75% - 82%

From the figure 4-9 above, the optimum bitumen content was found equal to be 5.5% which was calculated using the following as specified by Asphalt Institute.

Bitumen content at the maximum stability = 5.5 %

Bitumen content at the maximum value of bulk density = 5.5%

Bitumen content at the median per cent of air voids = 5.4%

Optimum Bitumen Content (OBC) =  $\frac{5.5+5.5+5.4}{3} = 5.47$  (5.5 approximately).

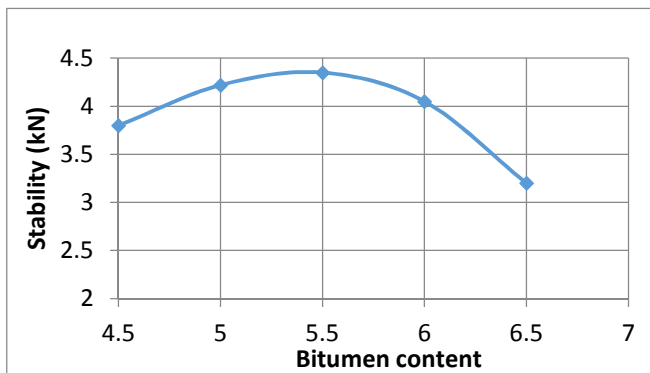


Figure 4: Stability vs bitumen content

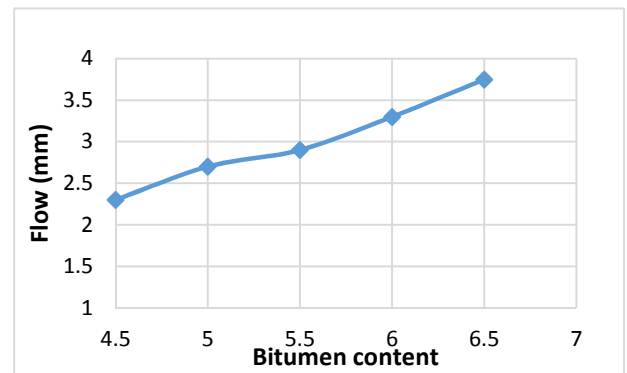


Figure 5: Flow vs bitumen content

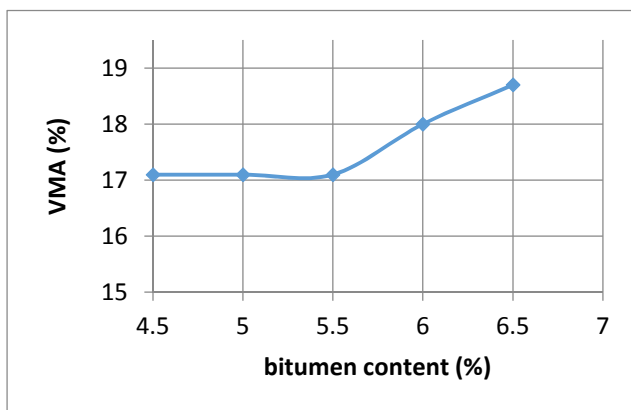


Figure 6: VMA vs bitumen content

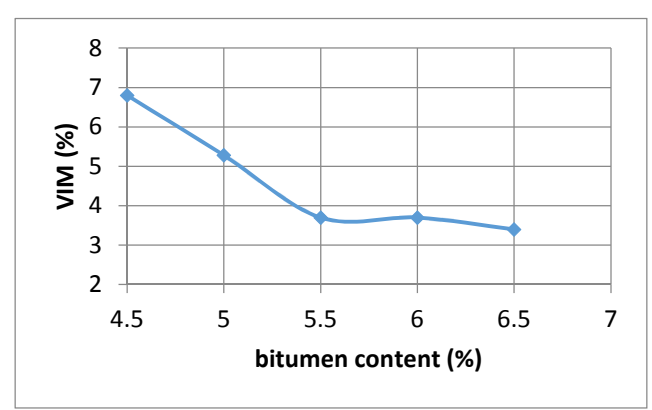


Figure 7: VIM vs bitumen content



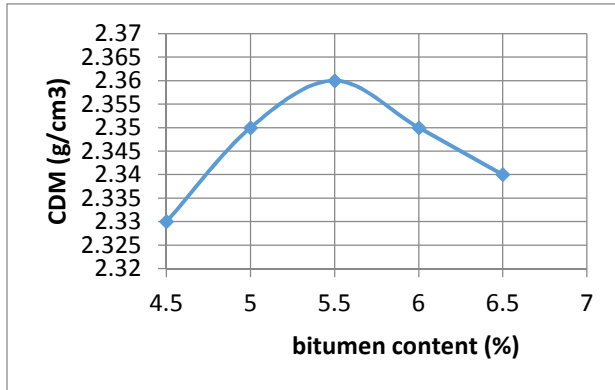


Figure 8: CDM vs bitumen content

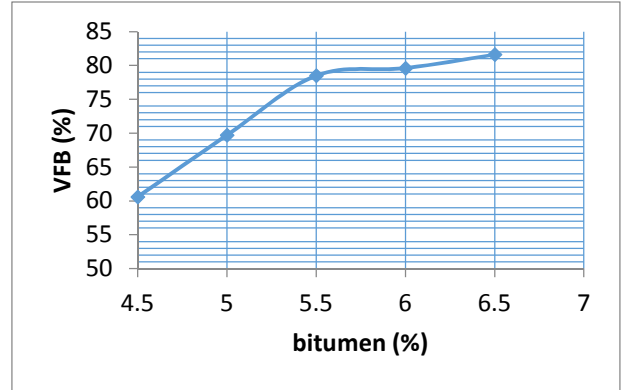


Figure 9: VFB vs bitumen content

**Marshall Test Results at Varying Percentage Replacement of Cement with Oil palm mesocarp fibre ash (OPMFA) at Optimum Binder Content of 5.5%**

The results of stability-flow and volumetric analysis (VIM; void in mix, VMA;

void in mineral aggregate and VFB; void filled with bitumen) at the varying replacement of cement with OPMFA (5%, 10%, 15%, 20%, 25%, and 30%) are shown in Figures 10 to 15. The optimum bitumen content of 5.5% was used in all the mixtures.

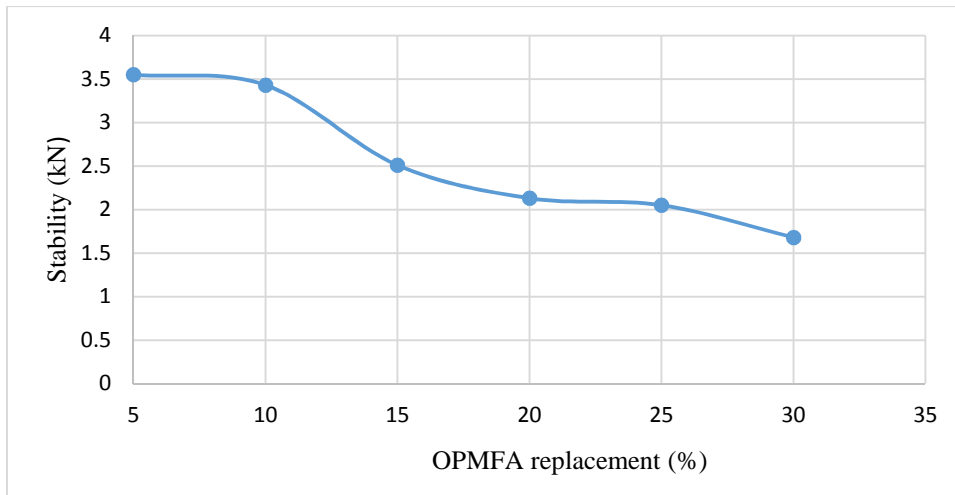


Figure 10: Graph of Stability against oil palm mesocarp fibre ash (OPMFA) content

The stability of the specimen is the maximum load required to produce failure of the specimen when the load is applied at a constant rate and temperature of 60°C. From figure 10 above, it was observed that the maximum stability of asphalt mix is 3.55kN at 5 % OPMFA content. The stability

values decrease from 3.55kN at 5 % OPMFA content to a value of 1.68 kN at 30% replacement of cement with OPMFA. The decrease in stability as the OPMFA content increases could be attributed to the low specific gravity of OPMFA compared to that of cement which did not allow the OPMFA to



fill up void spaces, thus, making the mix less stiff. Only the stability result obtained 5% replacement of cement with OPMFA meets

the specification of Nigerian General Specification for Roads and Bridges.

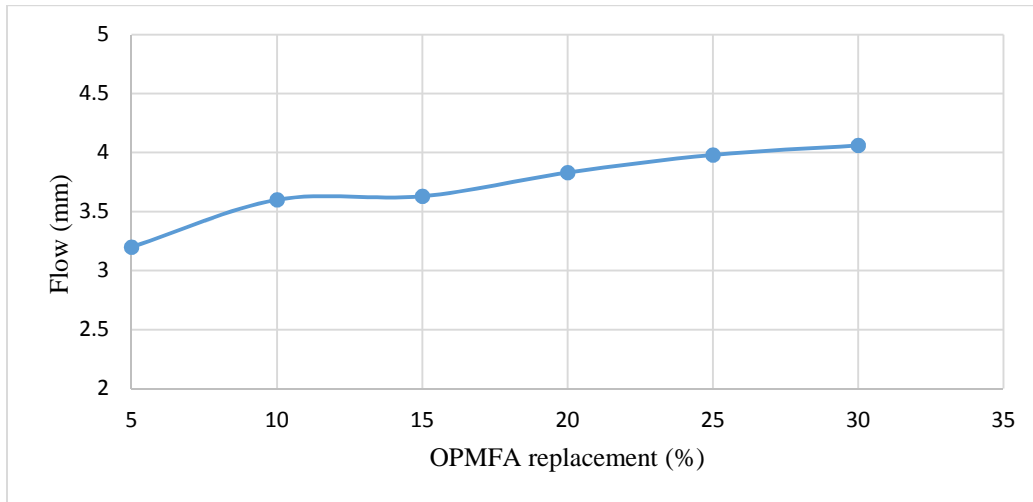


Figure 11: Graph of Flow against Oil palm mesocarp fibre ash (OPMFA) content

The results of flow presented in Fig. 11 above shows that the flow value increases from a value of 3.2mm at 5% OPMFA contents to 4.06mm at 30% OPMFA contents. This result is expected because the decreasing stability with increasing OPMFA content could result in increasing flexibility

of the mix, thus, inability to resist load. The different percentages of OPMFA contents meet the 2mm - 4mm requirements for the Nigerian General Specification for Roads and Bridges specifications, though, at 30% OPMFA contents 4.06mm was recorded.

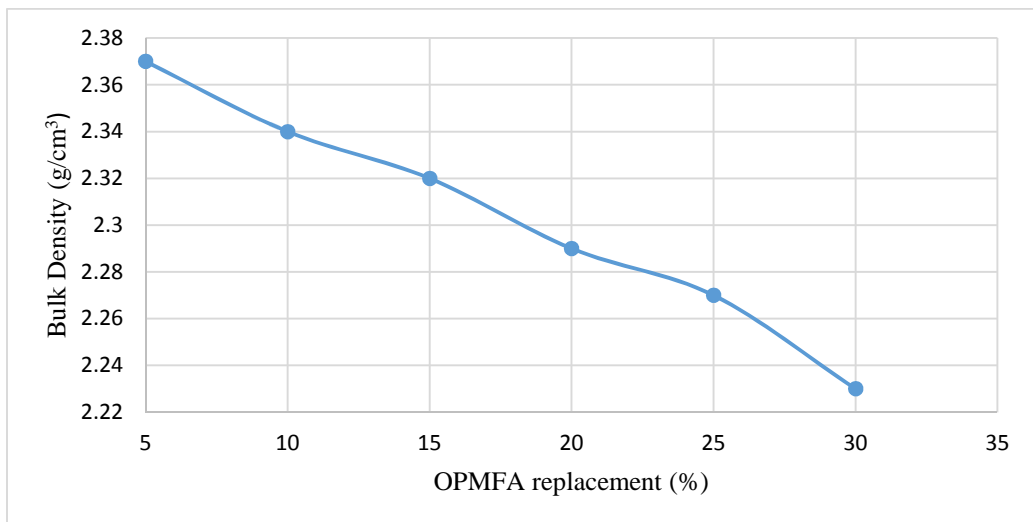


Figure 12: Graph of Bulk density against Oil palm mesocarp fibre ash (OPMFA) content



Figure 12 represents the bulk density results for different OPMFA contents. From the figure above it was observed that the maximum bulk density decreases from a value of 2.37g/cm<sup>3</sup> at 5%

OPMFA contents to 2.23 g/cm<sup>3</sup> at 30% OPMFA contents. This reduction in bulk gravity could be due to the low specific gravity of the OPMFA.

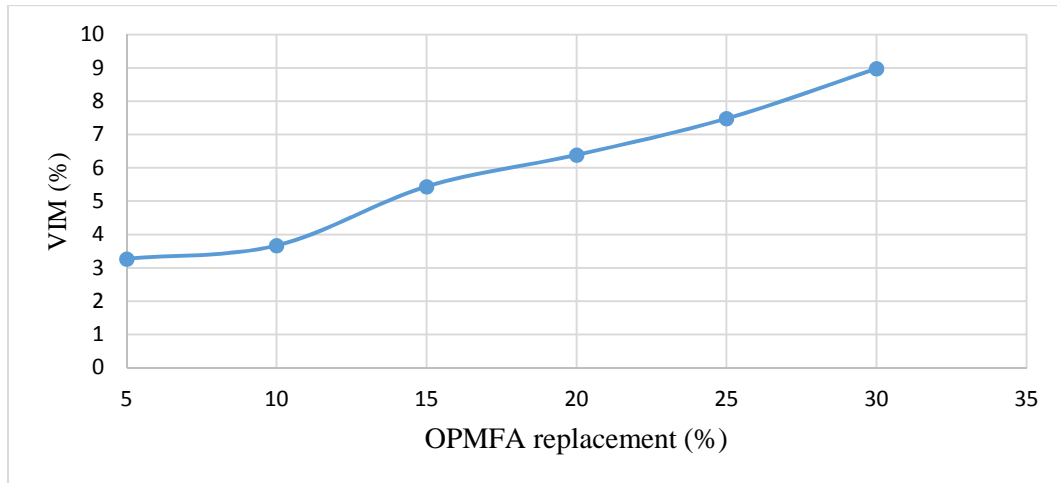


Figure 13: Graph of Void in Mix against Oil palm mesocarp fibre ash (OPMFA) content

The total volume of air expressed as percentage of the bulk volume of the compacted mixture is the void in mix (VIM). From Figure 13, it was observed that the void in mix increased from 3.27% at 5% to 8.98%

at 30% OPMFA contents. Only replacement of cement with OPMFA up to 10% meets the requirements of 3-5% of the Nigeria Specification for Roads and Bridges.

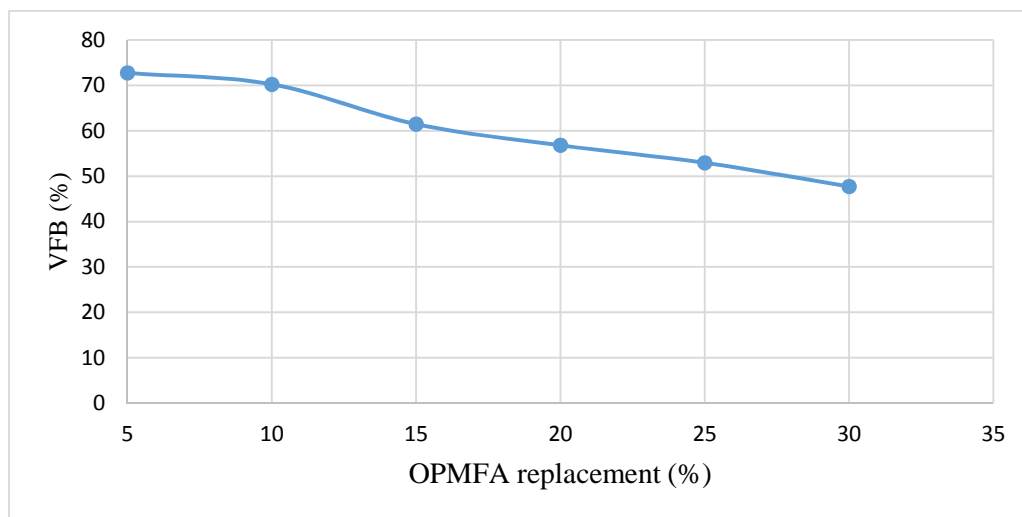
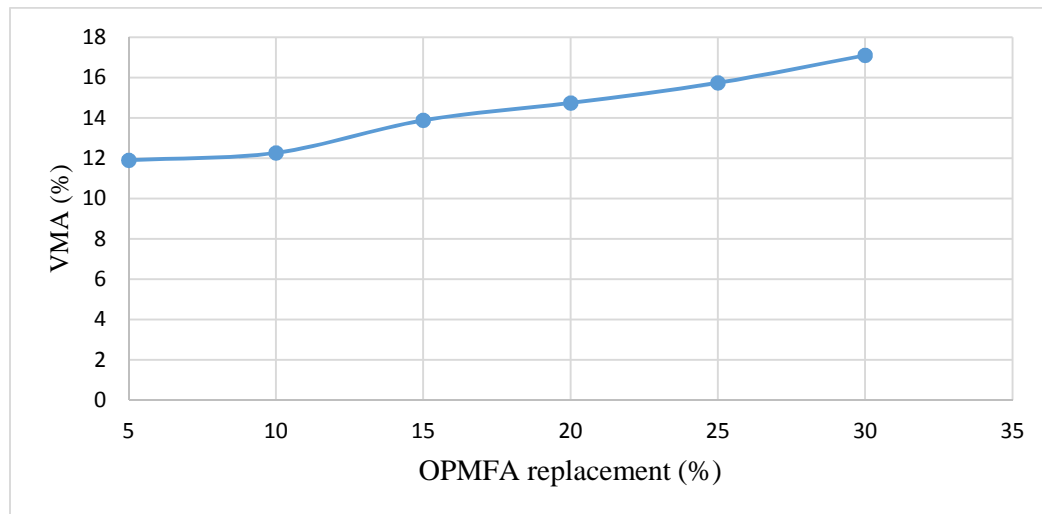


Figure 14: Graph of Void Filled with bitumen against Oil palm mesocarp fibre ash (OPMFA) content



From Figure 14, it is observed that the VFB decreases gradually as the OPMFA content increases and that is created more of voids in the asphalt mix because the bitumen content available isn't sufficient to bind the mineral aggregates together. From

the graph above it can be deduced that at 5% OPMFA content the VFB is 75% which satisfies the Nigerian general specification for road and bridges 1990 of 75%-82% for wearing course.



**Figure 15:** Graph of Void in Mineral aggregate against Oil palm mesocarp fibre ash (OPMFA) content

The VMA increases from 11.9% at 5% to 17.1% at 30% OPMFA content. This can be attributed to the excess OPMFA present in the mix which the bitumen cannot sufficiently coat to bind with other mineral aggregates. Generally in marshal test, the VMA decreases with increase in bitumen content until a minimum value of VMA is obtained (Shuaibu et al., 2019). Any further increase of bitumen will increase VMA, indicating that the asphalt structure is becoming overfilled with bitumen, and result in been susceptible to plastic deformation (ORN 10, 2003).

### CONCLUSION

Based on the experimental results obtained in this study, the following conclusion can be drawn:

1. The results of physical properties testing conducted on bitumen conforms to those of the ASTM standard specifications for the design of hot mix asphalt. Thus, the bitumen meets its requirements for use in hot mix asphalt production.
2. The physical properties testing conducted on fine and coarse aggregates are within the limits of ASTM and BS specifications. Thus, the aggregates meet the strength, toughness, hardness and resistance to wear requirements for use in asphalt concrete production.
3. The physical and chemical (X-Ray Fluorescence XRF test) property tests performed on Oil palm mesocarp fibre ash (OPMFA) confirmed it is a pozzolana of class



N according to ASTM C618 requirement and suitable for use as filler in asphalt concrete production.

4. The stability, and flow, values obtained at 5% replacement of cement with OPMFA at 5.5% bitumen content meet the specifications of Nigerian general specifications for Roads and Bridges.

#### RECOMMENDATION

1. Oil Palm Mesocarp fibre Ash (OPMFA) upto 5% is recommended to replace cement filler in HMA production.
2. To increase the amount of (OPMFA) to be used in HMA production, a ternary blend of (OPMFA) and another waste ash can be explored.

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