THE EXAMINATION OF METAKAOLIN AS A PARTIAL REPLACEMENT OF THE FILLER MATERIAL IN ASPHALT CONCRETE PRODUCTION

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ABSTRACT

Asphalt concrete is a mixture of binder, aggregates and filler in different relative proportions. Its design with other engineering materials is mainly dependent on the selection of appropriate constituent materials. The aggregate serves as reinforcement and add strength to the overall composite material while the mineral fillers which play a dual role in the mixtures act as a part of the mineral aggregate by filling the voids between the coarser particles in the mixtures and matrix that cements larger binder particles together. Metakaolin, mineral filler is used in this research being a pozzolanic in nature. This research aimed at examining the suitability of metakaolin as a partial replacement of filler material (stone dust) in asphalt concrete with percentage replacement of metakaolin at 5%, 10%, 15%, 20% and 25% used. The asphalt constituents were subjected to various standard tests in accordance with American Society for Testing and Materials (ASTM). Optimum bitumen content of 5.5% was determined when the values of marshal stability (maximum), void in mix and compacted density (maximum) were 8KN, 4.50% and 2.60 gm/cm^3.

Keywords: *Asphalt concrete, metakaolin, aggregates, optimum bitumen content, compacted density*

INTRODUCTION

Asphalt concrete is a composite materials made of bitumen, aggregates and filler commonly used to surface roads, parking lots and airports. Bitumen is a sticky, black and highly viscous liquid or semi-solid form of petroleum. It constitutes 5 to 10% by weight of the total mixture occurred in the natural deposits and about 70% of it is used in road construction as glue or binder mixed with aggregate particles to produce asphalt concrete beside being bituminous waterproofing products used as roofing felt and sealing flat roofs (Sorensen and Wichert, 2009). The design of asphalt paving mix with other engineering materials is mainly depends on the selection of appropriate constituent materials to obtain the desired properties in the finished pavement structure so as to provide safe, economical, durable, and smooth pavements that capable of carrying the anticipated loads. The aggregate serves as reinforcement and add strength to the overall composite material and constitute of about 90 to 95% by weight of the total mixture (concrete credentials, 2010).

Mineral fillers play a dual role in asphalt mixtures. They act as a part of the mineral aggregate by filling the voids between the coarser particles in the mixtures, thereby strengthen the asphalt mixture and when mixed with asphalt, fillers form mastic, a high-consistency binder or matrix that cements larger binder particles together. The major portion of the filler mostly remains suspended in the binder while a smaller portion becomes part of the load bearing framework (Harris and Stuart, 1995; Harrigan, 2011). It has the ability to increase the resistance of particle within the mix matrix and/or works as an active material when it interacts with the asphalt cement by changing the properties of the mastic (Kalkattawi, 1993) and workability (2012). A well-built backbone for the mixture is provided by the good packing of the coarse aggregate, fine aggregate and filler (Vavrik et al., 2002; Qiu, 2006). In selecting the filler, the quantity to be added depends on the amount of filler present in the aggregate, desired reduction in voids, the extent to which additional increment will decrease the OBC in the mix (Malhotra, 1986).

Many researchers have carried out investigations extensively by the use of several industrial wastes which are pozzalanic in nature as mineral fillers both in concrete and hot mix asphalt productions such as crushed stone dust, cement kiln dust ((Talal *et al*., (2013), fly ash, furnace steel slag (Farag *et al*., 2015) and rice husk ash) across the world. The use of these wastes was to sanitize the environment and minimizing the cost of disposal.

Previously, researchers have shown a lot of interest in Metakaolin as it has been found to possess both pozzolanic and microfiller characteristics (Poon *et al.,* 2001). Metakaolin is neither the by-product of an industrial process nor is it entirely natural. It is produced by heat-treating (calcinations of the high quality kaolin clay) kaolin, one of the most abundant natural minerals under carefully controlled conditions at a temperature of about 650 - 900ºC and a heating time of 90 minutes (Maruthachalam *et al*., 2012) to refine its colour, remove inert impurities, and tailor particle size such, a much high degree of purity and pozzolanic reactivity can be obtained. It has been used extensively in several ways. It has also been used successfully for the development of high strength self-compacting concrete using mathematical modeling (Dvorkin *et al*., 2012), shortening setting time (Murray, 2000; Murali *et al*., 2012; Ding et al, 1997) and decreasing autogenous shrinkage (Tazawa and Miyazawa, 1995). According to Murali *et al*., (2012), the use of 7.5% replacement Metakaolin in concrete effectively enhanced the strength properties and increased the compressive strength of concrete by 14.2%, the split tensile strength by 7.9% and flexural strength by 9.3%. Murana *et al*., (2014) among the others also studied the performance of metakaolin as partial replacement of cement in Hot Mix Asphalt and concluded that Metakaolin is a pozzolana and conforms to the requirement which has great potential for use in concrete.

The objective of the study was to investigate the effect of metakaolin as filler in the production of asphalt concrete.

MATERIALS AND METHODS

Materials

Materials used were coarse and fine aggregates, filler materials (Crushed stone dust and metakaolin), and binder-bitumen. The aggregates were obtained from Civil Engineering Department, FUNAAB. The bitumen used was obtained from Kopek Construction Company while raw kaolin was obtained from a site at km 9, Ajebo road, Abeokuta with the coordinates N7°8'29.68", E3° 26'9.89"and was heat-treated at 650°C for 90 minutes at Biotechnology centre in Federal University of Agriculture, Abeokuta.

Methods

Physical properties of bitumen, coarse aggregate, fine aggregate, crushed stone dust and the chemical properties of metakaolin were determined. The components of the asphalt were subjected into series of tests in accordance with the standard specifications namely:

Tests on bitumen (Penetration test (ASTM D5), Flash and fire point test (ASTM D92) and Specific gravity (ASTM D70).
Chemical properties of metakaolin (ASTM C618)
Specific gravity of the aggregates (ASTM C136), particle size distribution (BS 812-103.2).
Determination of optimum bitumen content suitable for the selected design for various sets of specimens were made at 4.5%, 5%, 5.5% and 6% bitumen contents. And the asphalt core partially replaced with metakaolin at 5, 10, 15, 20 and 25% were examined (ASTM D1559-63T). Marshall Test (soil laboratory of the Civil Engineering department of the University of Ibadan.

RESULTS AND DISCUSSION

Tests on Bitumen

The test results obtained were as shown in Table 1. They were within the limits of the code specifications; therefore the bitumen was used for the investigation. This bitumen was of Penetration code 80/100.

Table 1: The summary of the results of the Preliminary tests carried out on bitumen compared with Standard specification

Test	Specification by code			Result obtained
	40/50	60/70	80/100	
Penetration at 25oC	40-50	60-70	80- 100	91.33 mm
Flash point	232	232	225	273^0C
Fire point				303^0C
Specific gravity	0.97 - 1.02	0.97 - 1.02	0.97 - 1.02	1.01

The specific gravity test on Aggregate materials (coarse, fine and fillers). The results of the tests carried out on the aggregate materials were presented in Table 2 and compared with the standard specifications. The values obtained were within code of specifications and suitable for HMA design.

Table 2: Summary of the values for the specific gravity of each material used

Materials	Specification	Specific gravity value
Coarse aggregate	2.6 - 2.9	2.83
Fine aggregate (sharp sand)	2.6 - 2.9	2.47
Filler material (stone dust)		2.63
Metakaolin		2.51

Particle Size Distribution Curves for Aggregates. The graphs of particle size distribution performed on the aggregates (Coarse and Fine) were as shown in Figures 1 and 2.

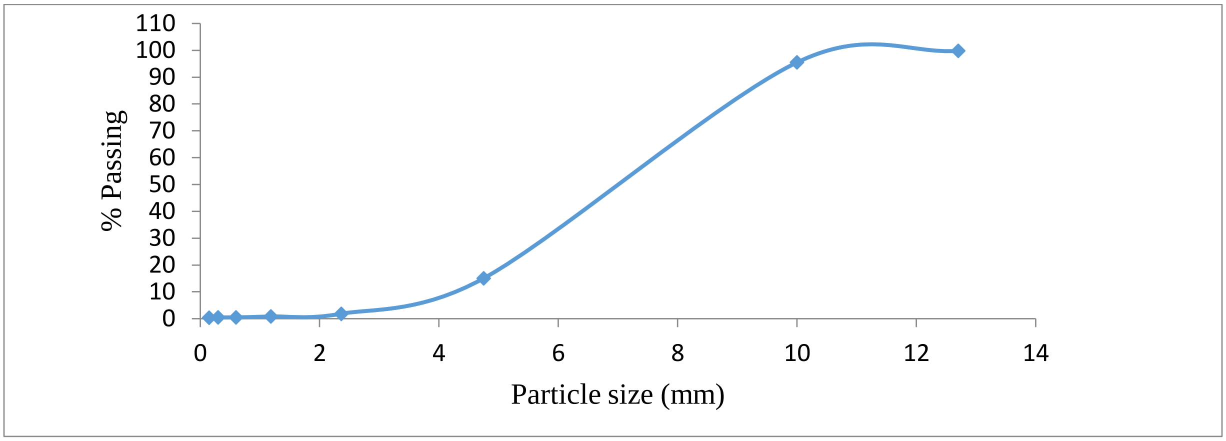

Figure 1: Sieve analysis curve for the coarse aggregate

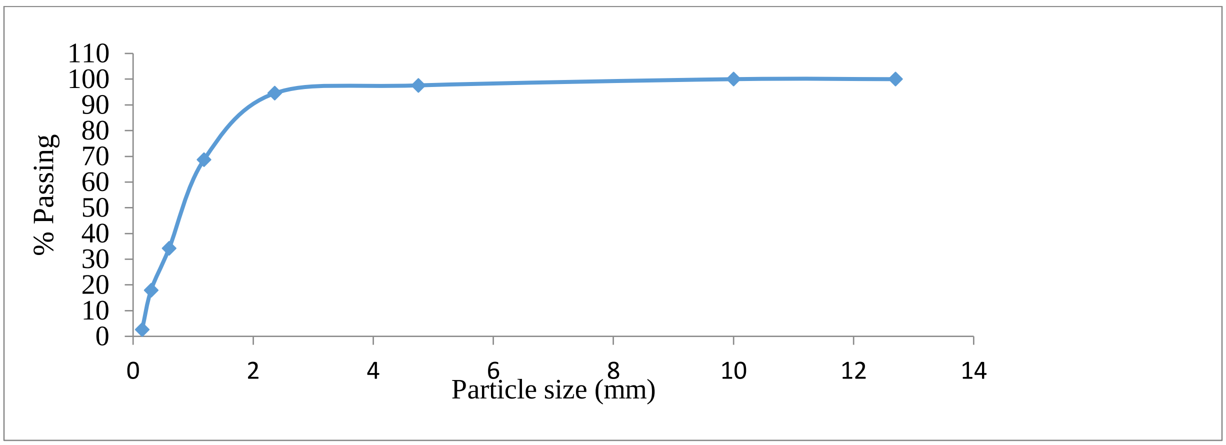

Figure 2: Sieve analysis curve for the fine aggregate (sharp sand)

Both the coarse and fine aggregates used were poorly graded: Cc = 1.81, Cu = 1.05 and Cc = 5.0 Cu = 1.25 respectively.

Metakaolin

The collected sample of Metakaolin was taken for elemental analysis using X-ray fluorescence energy dispersive. The analysis was carried out in accordance with ASTM, 2001 to determine the oxide composition of MK. and the result is as shown in Table 3.

Table 3: Chemical composition of metakaolin

S/N	Chemicals	Percentage (%)
1	SiO_2	62.82
2	Al_2O_3	28.81
3	Fe_2O_3	1.12
4	Na_2O	1.57
5	K_2O	3.46
6	CaO	0.05
7	MgO	0.15
8	MnO	0
9	SO_3	0
10	P_2O_5	0
11	TiO_2	0.42

12	Moisture	0
13	Loss on ignition (L.O.I)	1.58

The metakaolin used in this research was compared with ASTM Specification (Table 4), and observed to be in class N, hence, it can fit into Hot Mix Asphalt design and can be used as supplementary cementitous material (Velosa *et al*., 2009).

Table 4: Comparison of test result on Metakaolin with ASTM Standard

Mineral Admixture Class	N	F	C	Test Result
SiO2 + Al2O3 + Fe2O3 min, %	70	70	50	82.75%
SO3 Max,%	4	5	5	0%

Asphalt concrete mix design

The total aggregate proportion used for this project was in accordance with the Federal Ministry of Works and Housing specification and the curve was as shown in Figure 3. To determine the optimum bitumen content suitable for the selected design, various sets of specimens were made at 4.5%, 5%, 5.5% and 6% bitumen contents (Table 4) and an optimum bitumen content of 5.5% was obtained at maximum stability (8 kN), void in mix (4.50%) and maximum Compacted density (2.60 gm/cm^3).

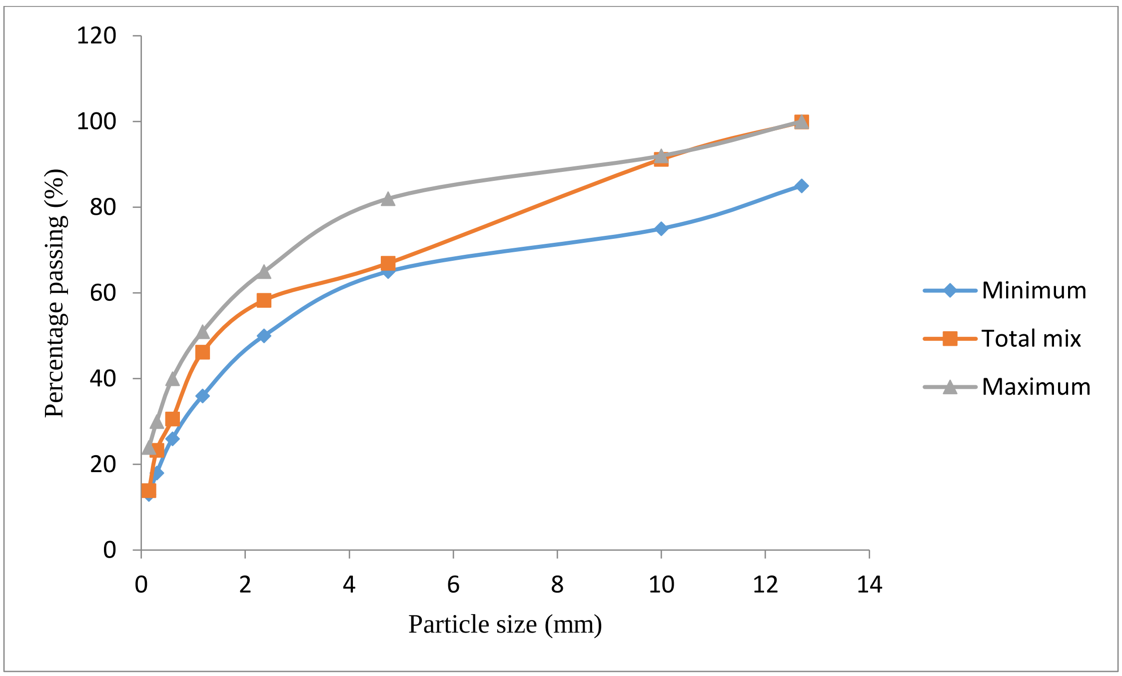

Figure 3: Asphalt concrete mix design.

Table 4: Summary of the properties of asphalt briquettes at different bitumen contents

Properties	Bitumen content (%)			
	4.5	5.0	5.5	6.0
Stability (kN)	6.65	7.80	8.00	7.32
Flow (mm)	2.20	2.32	2.65	2.91
VFB (%)	66.54	76.20	74.97	71.77
VMA (%)	37.55	21.85	13.5	23.38
VIM (%)	10.6	5.20	4.50	6.62
Compacted density (gm/cm^3)	2.08	2.50	2.60	2.46

Effects of metakaolin on Asphalt Properties

From Figure 4, it was observed that Marshall Stability increase with an increase in metakaolin content to a maximum value (50.21 kN) and started to drops with an increase in metakaolin content with an optimum bitumen content 5.5% for the stability of mix design. All the values obtained for Marshall stability at different metakaolin contents were found to be higher than the control samples (according to the Asphalt institute standard of a minimum of 8 KN) which means that the metakaolin has improved the quality of the asphalt mix in terms of the stability.

Effects of metakaolin on flow

It was seen from the table that the flow value increased from the 0% to 5% metakaolin replacements. But as the metakaolin content increased from 10% to 20%, the flow values decreased but then increased again at 25%, although all the values obtained were higher than the mix with 0% bitumen. This means that the metakaolin increased the quality of the mix in terms of the flow property (Table 5).

Table 5: Summary of the properties of asphalt briquettes at different metakaolin contents

Properties	Metakaolin content (%)					
	0	5	10	15	20	25
Stability (KN)	26.00	28.38	50.21	45.74	32.49	39.21
Flow (mm)	8.38	17.07	13.79	11.42	10.82	12.71
VFB (%)	76.20	67.62	75.63	82.24	81.65	43.85
VMA (%)	19.66	25.49	21.83	13.65	21.25	23.69
VIM (%)	4.68	8.26	5.32	2.43	3.90	8.30
Compacted density (gm/cm^3)	2.01	2.15	2.21	2.38	2.34	2.11

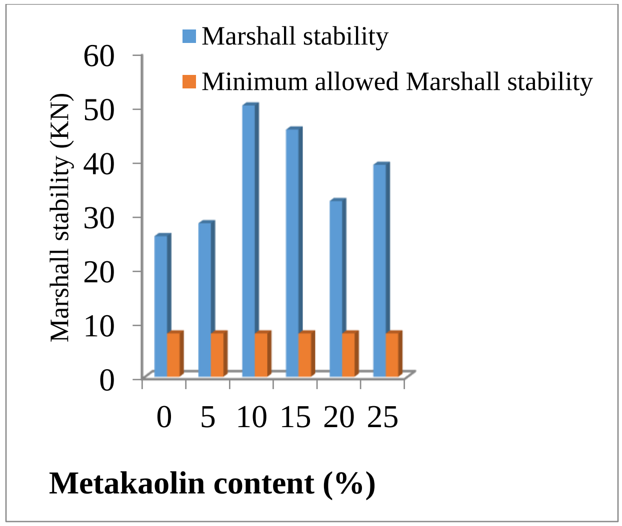

Figure 4: Marshall Stability with Metakaolin % replacement.

Effects of metakaolin on void in mix (VIM)

The VIM property of the asphalt at 15% was found to be the lowest (2.43%) while the highest value (8.30%) was obtained at 25% replacement with metakaolin (Figure 5). Comparing the values obtained with Asphalt institute standard specifications, only percentage replacement with 15% and 20% metakaolin (2.43% and 3.90% respectively)satisfied the maximum VIM requirement (5%) for heavy traffic highway.

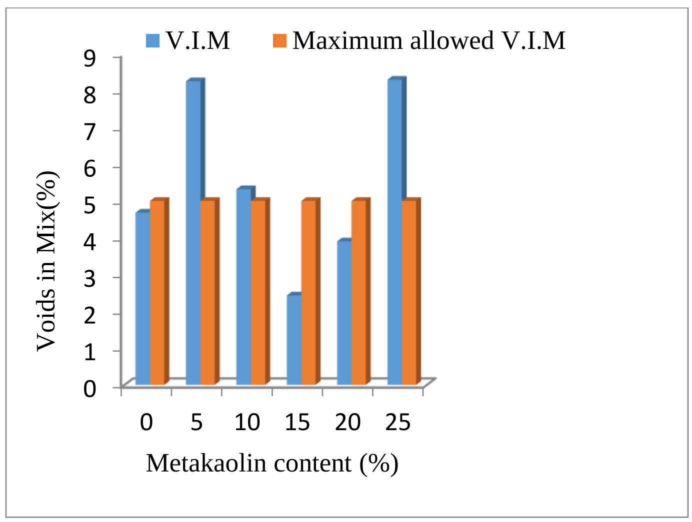

Figure 5: Metakaolin and Void in Mix

Effects of metakaolin on voids filled with bitumen (VFB)

The values obtain for the VFB satisfied 75% minimum value by the Asphalt Institute recommendation requirement except at 5% and 25% replacement 67.62% and 43.85% respectively (Figure 6)

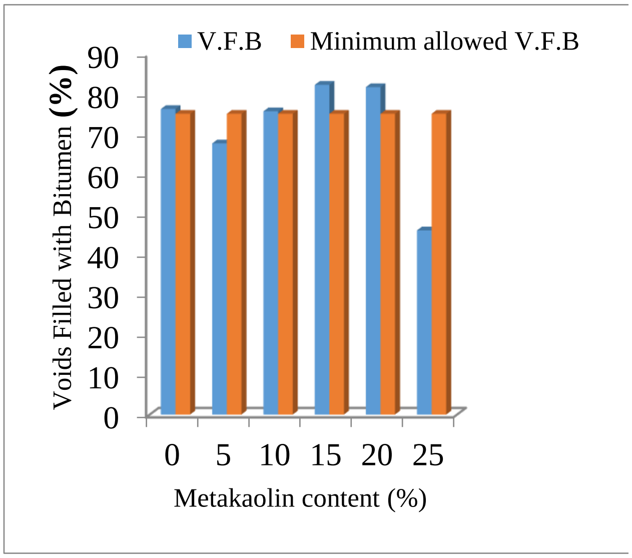

Figure 6: Voids Filled with Bitumen

Effects of metakaolin on compacted density of the mix

The compacted density of the mix increased with an increase in % replacement with metakaolin and had the maximum value (2.38gm/cm^3) at 15% (Figure 7). Further increase in metakaolin content led to reduction of the compacted density.

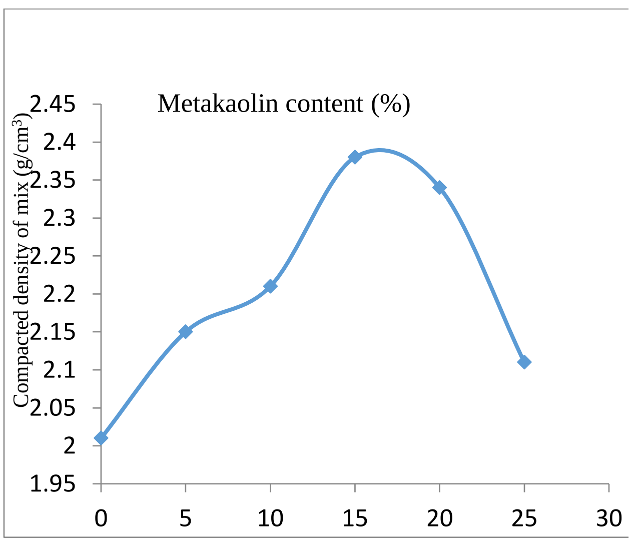

Figure 7: Effects of Metakaolin on Compacted density of the Asphalt

CONCLUSION

The conclusions drawn from this research work are:

1. The high values of the SiO_2 and Al_2O_3 shown in the properties of the metakaolin revealed that it can be classified as a suitable pozollanic (class N) material that can be used for asphalt concrete production.
2. Metakaolin gave an improvement on the void in mix (VIM) property of asphalt cores at 15% and 20% replacement.
3. The metakaolin replacements showed improved Marshall Stability of asphalt cores for all the replacement percentages.
4. For the voids filled with bitumen of asphalt concrete, metakaolin showed desirable properties at 10%, 15% and 20% replacements.
5. Comparing the stability, void in mix and void filled with bitumen results for this research with the Asphalt Institute standards, it can be concluded that metakaolin can be used as a partial replacement of filler between 15% and 20%.

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