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Partial replacement of cement with rice husk ash (RHA) as filler in asphalt concrete design

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Abstract

This work focused on the use of Rice Husk Ash (RHA) as filler in Hot Mix Asphalt (HMA). HMA design was carried out using Marshall Stability method. Several trial mixes with bitumen contents of 4.5%, 5.5%, 6.5% and 7.5% were produced to obtain the Optimum Bitumen Content (OBC). The investigation focuses on the partial replacement of cement with RHA using the obtained OBC in the following order 0%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, 20%, 22.5%, and 25%. A total of forty-two (42) mix specimens were prepared, twelve (12) of these were compacted at each percentage of bitumen content to determine the OBC and 30 specimens were used to determine the optimum RHA content in terms of the HMA strength. From the Marshall Stability-flow test analysis, the sample prepared with 10% RHA as filler with an OBC of 5.5% satisfied the provision of the Standard Specification requirement by Asphalt Institute.

Keywords: Hot Mix Asphalt, Marshall Method, Bitumen, Rice Husk Ash, Cement.

1. Introduction

The safe disposal of waste materials is an increasingly economic and environmental concern in the several parts of the world (Ahmed & Lovell, 1993). The production of non-degradable waste materials, combined with a growing consumer population, has resulted in a waste disposal crisis. One solution to this crisis lies in the recycling of the waste materials into useful by-products (Kandhal & Khatri, 1992).

Recently, there have been several reported uses of crop waste material for pavement construction. One of which is an investigation of the potential use of Rice Husk Ash (RHA) as a supplemental cementing material for the replacement of Portland cement in Portland Cement Concrete (PCC) mixtures (NAPA, 2001).

Supplementary Cementitious Materials (SCM) are often incorporated in Asphalt concrete mix to reduce cement contents, improve workability, increase strength and enhance durability. Early SCMs consisted of natural, readily available materials such as volcanic ash or diatomaceous earth. More recently, strict air-pollution controls and regulations have produced an abundance of industrial by-products that can be used as SCM such as fly ash, silica fume and blast furnace slag. Most often an SCM will be used to replace a portion of the cement content for economical or property-enhancement reasons (Neuwald, 2010).

Rice husk is an agricultural residue which accounts for 20% of the 649.7 million tons of rice produced annually worldwide. The chemical composition of rice husk is found to vary from one sample to another due to the differences in the type of paddy, crop year, climate and geographical conditions. Burning of RH in ambient atmosphere leaves a residue, called rice husk ash. The non-crystalline silica and high specific surface area of the RHA are responsible for its high pozzolanic reactivity (Anwar, et al., 2001).

It has been discovered that rice husk ash is efficient as a pozzolanic material; it is rich in amorphous silica, 88.32% (Mahmud, et al., 2009).

Research has shown that RHA has been used in lime pozzolana mixes and could be a suitable partly replacement for Portland cement (Nicole, et al., 2000); (Sakr, 2006); (Sata, et al., 2007)).

2. Materials and Methods

2.1 RHA used in the Production of Asphalt

RHA and palm oil fiber have been used as filler for stone mastic asphalt. The physical characteristics of stone asphalt with RHA and palm oil fiber were favourable for surfacing in road construction. The result of asphalt with RHA and palm oil fiber as filler and binder passed standard specifications (Jeffrey, et al., 2002).

2.2 Materials

Materials used are the constituent materials of asphalt concrete; bitumen, aggregate (fine and coarse) and filler material (cement and rice husk ash).

2.3 Tests on material

Tests to determine the engineering properties of bitumen and aggregates, chemical composition of RHA and ordinary Portland cement were conducted.

2.3.1 Tests on Coarse Aggregate

The following tests were carried out on aggregate in order to determine its suitability for use in the asphalt concrete: Sieve Analysis of Coarse Aggregates; Specific Gravity; Bulk Density and Void of Coarse Aggregate.

3. Results

3.1 Preliminary Tests on Bitumen

The result of the preliminary tests on Bitumen are as presented in Table 1.

Table 1: Test Results on Bitumen

TEST	UNIT	TEST RESULTS
Penetration at 25°C	mm	105
Viscosity at 60°C	mm³/s	121.83
Flash and Fire point	°C	259
Solubility	%	96
Ductility	cm	>100

3.2 Preliminary Tests on Filler Materials

3.2.1 Test on Cement and RHA

Dangote brand of ordinary Portland cement was used in the experiment. Some preliminary tests like setting times and soundness tests were carried out. The initial and final setting times were considered using cement and different percentages of rice husk (RHA).

Table 2: Initial and Final Setting Times of Cement and RHA

Cement (%)	RHA (%)	Initial Setting Time (min)	Final Setting Time (min)
100	0	122	183
90	10	136	227
80	20	154	255
70	30	165	275
60	40	213	350
50	50	281	402

3.2.2 Chemical Analysis of RHA and Cement

The chemical analysis of the samples was conducted at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, using minipal which is a compact energy dispersive X-ray spectrometer designed for the elemental analysis of a wide range of samples. The results of the analysis are as presented in Table 3.

Table 3: Chemical Analysis of RHA and Cement (Weight %).

Constituents	Concentration Unit in RHA	Concentration Unit in OPC
SiO_2	68.12	23.43
CaO	1.01	64.40
Al_2O_3	1.06	4.84
Fe_2O_3	0.78	4.08
K_2O	21.23	0.29
SO_3	0.137	2.79
LOI	18.25	5.68
Free Lime	-	1.50

3.3 Marshall Method of Asphalt-Concrete Mix Design

Optimum binder content is selected as the average binder content for maximum density, maximum stability and specified percent air voids in the total mix.

Table 4 Summary of Marshall Analysis At 0% RHA/ 100% OPC

Bitumen content (%)	Stability (kN)	Flow (mm)	CDM (g/cm³)	VIM (%)	VMA (%)	VFB (%)
4.5	3.97	2.43	1.78	28.51	36.22	21.31
5.5	6.70	3.0	1.49	39.40	47.27	16.63
6.5	2.73	5.64	1.53	36.78	46.33	20.61
7.5	3.81	3.56	1.55	35.15	46.75	24.81
8.5	2.96	4.1	1.65	30.08	43.88	31.45

Table 5 Summary of Marshall Analysis At 5.5% Optimum Bitumen Content

RHA content (%)	Stability (kN)	Flow (0.25 mm)	CDM (g/cm³)	VIM (%)	VMA (%)	VFB (%)
0.0	6.70	3.0	1.49	39.	47.	16.

				40	27	63
5.0	5.75	3.06	1.80	27.13	35.93	24.49
7.5	7.27	2.73	1.77	28.63	37.17	22.98
10.0	7.63	2.19	1.78	28.23	36.77	23.23
12.5	5.02	2.56	1.79	27.82	35.40	23.57
15.0	4.46	3.06	1.78	28.23	36.75	23.19
17.5	5.30	2.19	1.79	27.82	36.38	23.53
20.0	4.56	2.54	1.80	27.13	35.79	24.20
22.5	5.85	2.08	1.81	36.46	45.23	19.39
25.0	3.45	2.19	1.81	36.46	45.07	19.10

4. ANALYSIS AND DISCUSSION OF RESULTS

4.1 Tests on pure bitumen

The results obtained presented in Table are now compared with the standard code of practice to assess for its quality for usage. The results obtained in the test conducted are within the limits of code specifications (see Table 6), therefore the bitumen can be judge as good for usage.

Table 6: Result of preliminary tests on bitumen

Test	Test Method (ASTM)	Specification by codes for penetration Grade*			Results obtained
		40/50	60/70	80/100	
Penetration at 25˚C (mm)	D5	40-50	60-70	80-100	98
Flash point and fire point (˚C) Min.	D92	232	232	219	240 and 259 respectively.
Solubility in carbon tetrachloride (CCl4) Min. (%).	D2042	99	99	99	99
Specific gravity at 25˚C Min.	D70	0.97-1.02	0.97-1.02	0.97 - 1.02	1.00
Ductility at 25˚C Min (mm)	D113	-	50	75	100
Viscosity(mm³/s)	D4402	220 - 400	120 - 250	75-150	138

4.1.1 Penetration Test

From Table Penetration Test result obtained (98mm), which falls within penetration grade 80-100. For the viscosity test carried out, the result obtained (138mm³/sec) conforms to the viscosity requirement (75-150mm³/sec) for penetration grade of 80-100. The flash and fire point result obtained (240˚C) conforms to the ASTM D92 requirement (219˚C) for penetration grade of 80-100. From the solubility test carried out, the Result obtained (99%) conforms to the ASTM D2042 requirement (99%) for penetration grade of 80-100. From the ductility test carried out, the result obtained (100mm) conforms to the ASTM D113 requirement (75mm) for penetration grade of 80-100. Based on the above discussion, it can be concluded therefore that the material is suitable for HMA design.

4.2 Tests on RHA

The test result obtained was compared with those specified by ASTM C 618-78 for use admixture in concrete.

Table 7: Comparison of test on rice husk ash with standard

Mineral admixture class				Test result
	N	F	C	
Silicon dioxide (SiO_2), plus aluminum oxide (Al_2O_3), plus iron oxide (Fe_2O_3) min, %	70.0	70.0	50.0	69.96
Sulfur trioxide (SO_3), max, %	4.0	5.0	5.0	0.14

From the table, it was observed that RHA is composed of several oxides and according to ASTM C618-78 which specifies that a material having a combined weight of silica, aluminum and iron oxides of a minimum value of 50% (for class C), 70%(for class N), 70% (for class F) by weight of fraction is considered a pozzolana. The Rice husk ash used for this research is of class C. Therefore, it can be said that RHA is pozzolanic and can be used as mineral filler in HMA design as a partial replacement of cement.

4.3 Test on cement

Table 8: Comparison of Test Result on the Cement with Standard

Property	Results	Code used	Code specification
Initial setting time (min)	122	BS EN 196 PART 3 (1995)	>45mins

Final setting time (hr-min)	3hrs 3mins	BS EN 196 PART 3 (1995)	<10hrs
Soundness (mm)	4.2	BS EN 196 PART 3 (1995)	<10mm
Specific gravity	2.43	ASTM C188	3.15

Therefore, since the standards are in agreement with the test result obtained, it is then concluded that the cement used for this study is an ordinary Portland cement and is suitable for engineering purposes.

4.4 Tests on Coarse and Fine Aggregate

4.4.1 Sieve Analysis Test

The graduation curve for both coarse and fine aggregates are shown in figures 1 and 2 below.

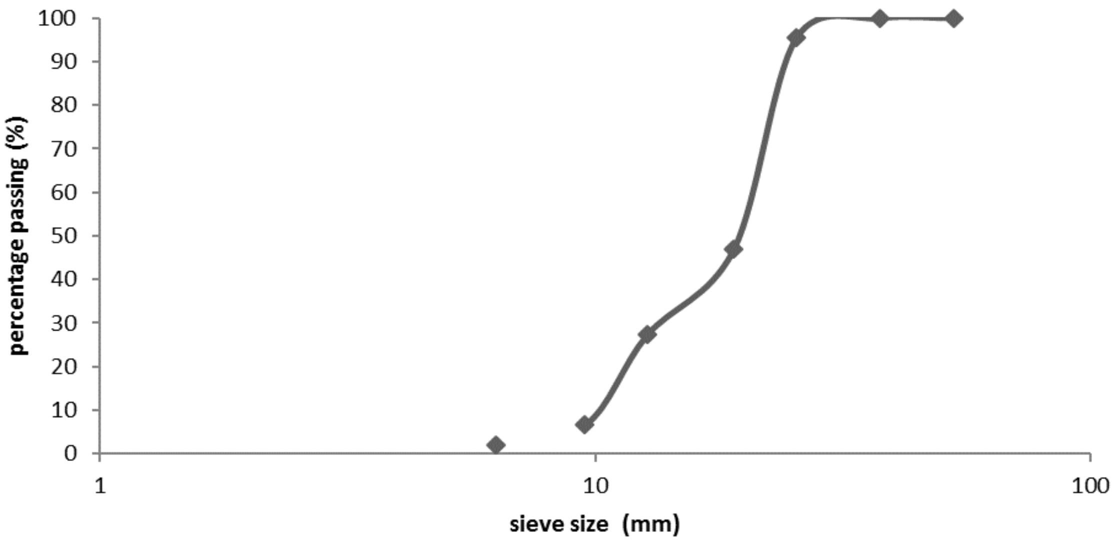

Figure 1: Graph showing the graduation curve of coarse aggregate

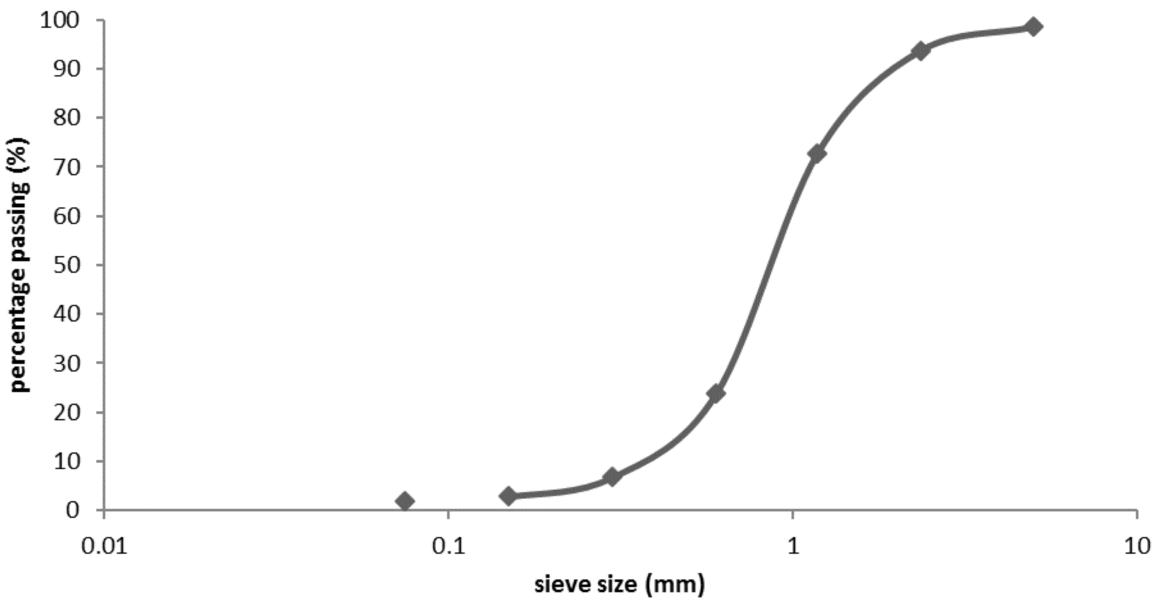

Figure 2: Graph showing the graduation curve of fine aggregate

The table below shows the strength properties which are measures of mechanical properties (crushing and impact tests) of the aggregate and specific gravity is a measure of aggregate density.

Table 9: Comparison of Test Results on Aggregates with Standards

Property	Unit	Test Result	Code used	Code specification
Aggregate crushing value	%	20.50	BS 882 PART112	<30
Aggregat	%	16.70	BS 882	<30

e impact value			PART11 1	
Specific gravity (Coarse)		2.70	ASTM C136	2.6-2.9
Specific gravity (Fine)		2.65	ASTM C136	2.6-2.9

The values obtained from the tests on aggregates are substantial typical value of Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV) and Specific Gravity (SG) for the aggregate favourable to the quoted code of specifications as such the aggregate is suitable for HMA design.

4.5 Marshall Test Result

The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60˚C. The flow value is the deformation that the test specimen undergoes during loading up to the maximum load. Flow is measured in 0.25mm units. In this test, an attempt is made to obtain optimum binder content for the type of aggregate mix used and the expected traffic intensity.

Table 10: Typical Marshall Mixture Design Criteria

Description	Type I Base course		Type II Binder or leveling course		Type III Wearing course	
	Min.	Max.	Min.	Max.	Min.	Max.
Marshall specimens (ASTM D 1559) No. of comp. Blows, each end of specimen	75		75		75	
Stability, kN.	2224		3336		6672	
Flow (0.25mm or 0.01 inch) (mm)	8 [2]	16 [14]	8 [2]	16 [14]	8 [2]	16 [14]
VMA Air voids, % Aggregate voids filled with bitumen, %	13 3 60 70	 8 80	14 3 65 70	 8 85	15 4 70 70	 6 85

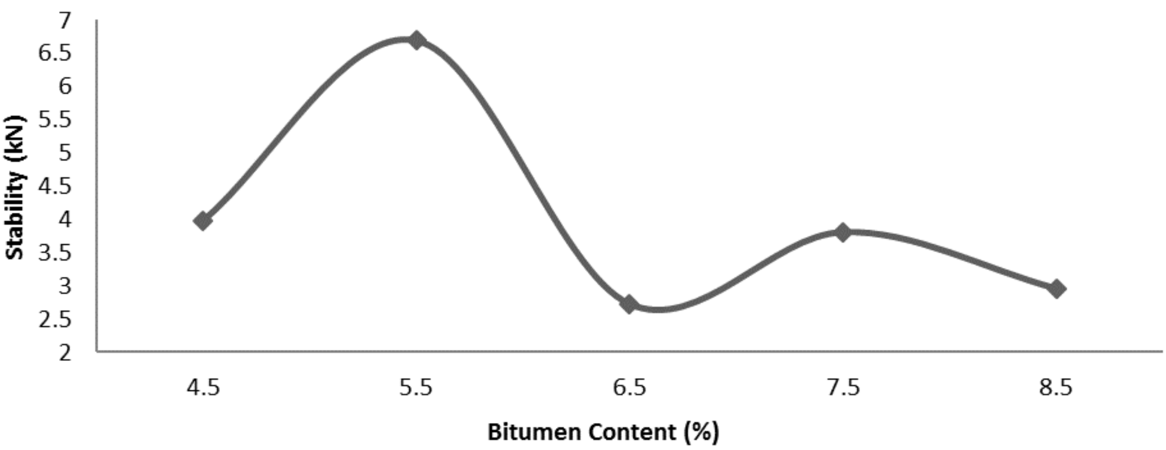

Figure 3: Graph of Stability against Bitumen Content

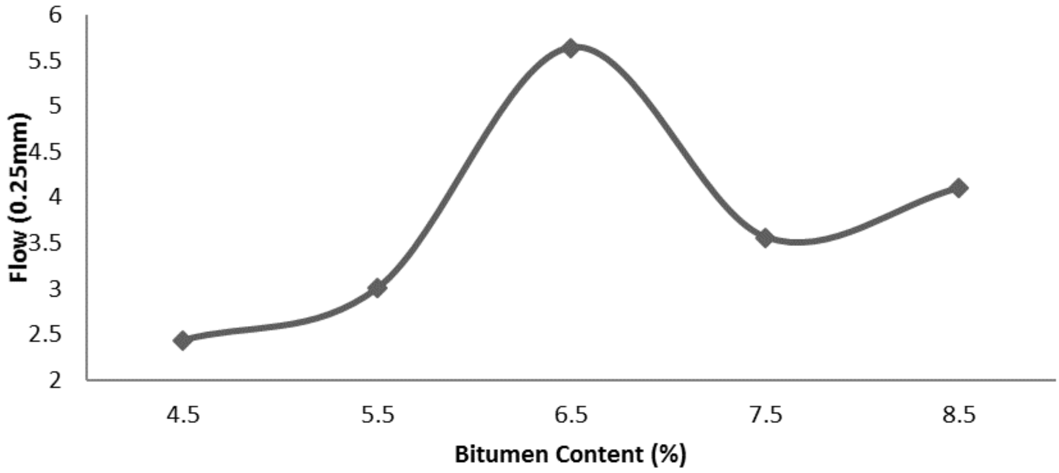

Figure 4: Graph of Flow against Bitumen Content

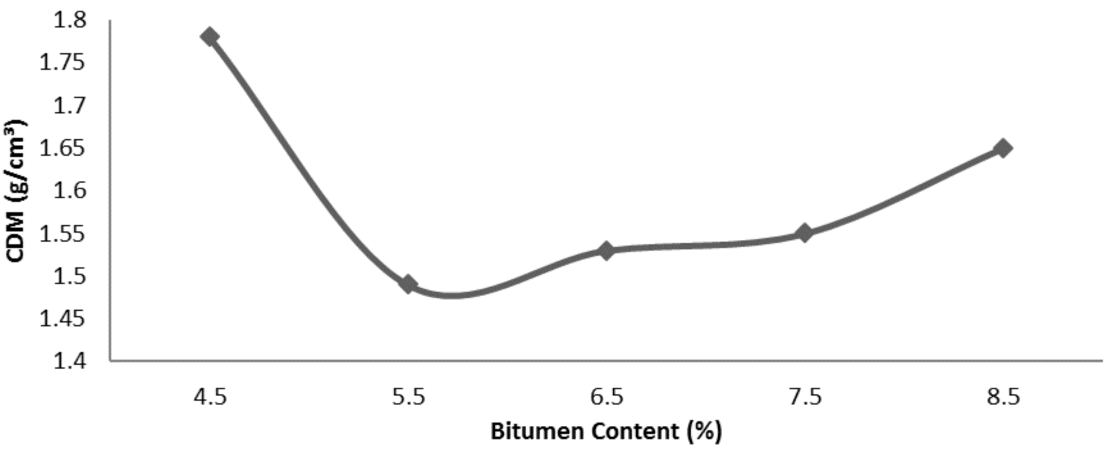

Figure 5: Graph of CDM against Bitumen Content

The stability of the sample increased initially up to a bitumen content of 5.5%, and then began to fall with an increase of bitumen content, as shown in figure 3. The stability of the sample was optimum at a bitumen content of 5.5% with a value of 6700N which is greater than the minimum value of 6672N specified by the standard as given in table 10 for heavy traffic.

The flow of the sample increased with increase in bitumen content up to a bitumen content, which is the conventional form, as shown in figure 4. The test yielded a maximum flow value of 5.64mm, which falls within the range of 2-14mm as specified by standard as shown in table 10 for a heavy traffic.

The compacted density of the mix increases at a bitumen content of 4.5%, and then it began to decrease with further increase in bitumen content, as shown in figure 5. The value at 4.5% bitumen content was gotten to be $1.78g/cm^3$.

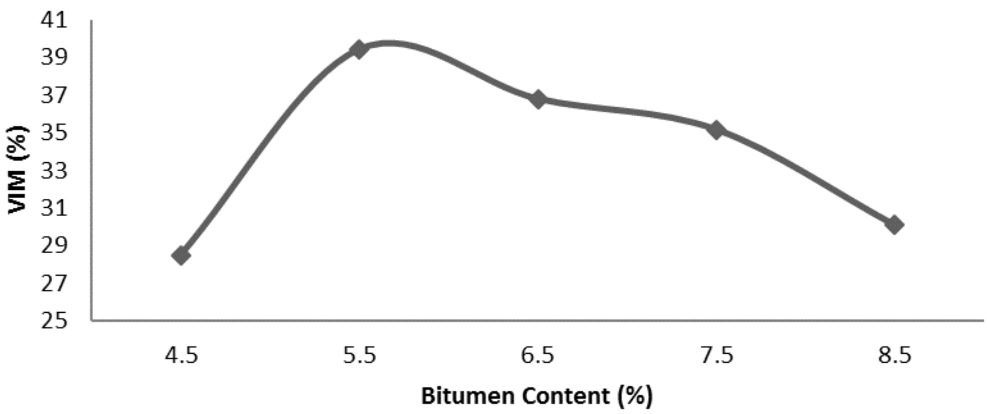

Figure 6: Graph of VIM against Bitumen Content

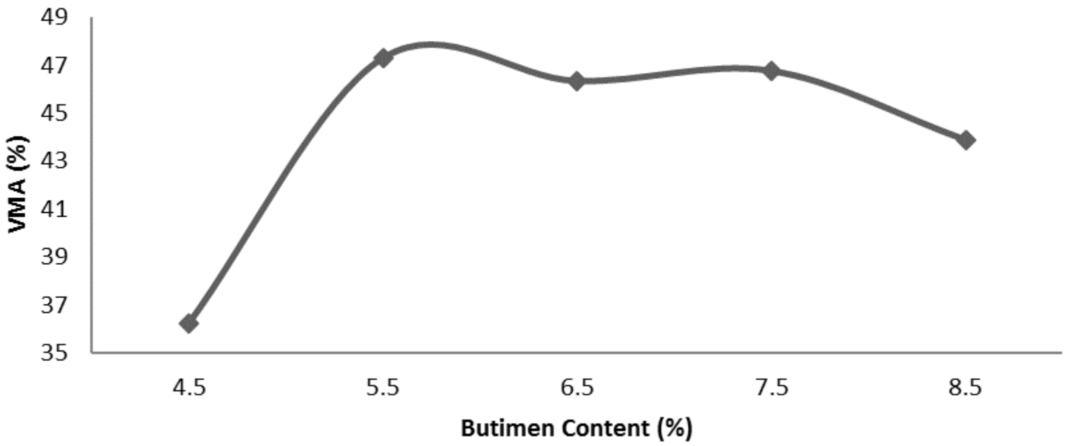

Figure 7: Graph of VMA against Bitumen Content

Table 11: Typical Marshal Mix Minimum VMA

		Minimum VMA (%)
(mm)	(inch)	
63	2.5	11
50	2.0	11.5
37.5	1.5	12
25	1.0	13
19	0.75	14
12.5	0.50	15
9.5	0.375	16
4.75	0.19	18
2.36	0.094	21
1.18	0.047	23.5

The volume of void in the mix obtained increased up to a bitumen content of 5.5%, and then it began to fall with further increase in bitumen content as shown in figure 6. The value for VIM at which stability is maximum was 36.78% and at a bitumen content of 5.5%.

The voids in mineral aggregates (VMA) increase with an increase in bitumen content, which gave a maximum value of 47.27% of void in the mixed aggregate as shown in figure 7. The value obtained is greater than the minimum value of 16% for a maximum aggregate size of 9.5 (used for the mix) as stated in table 11.

The maximum particle size used was 9.5mm; which implies that minimum VMA is 16%.

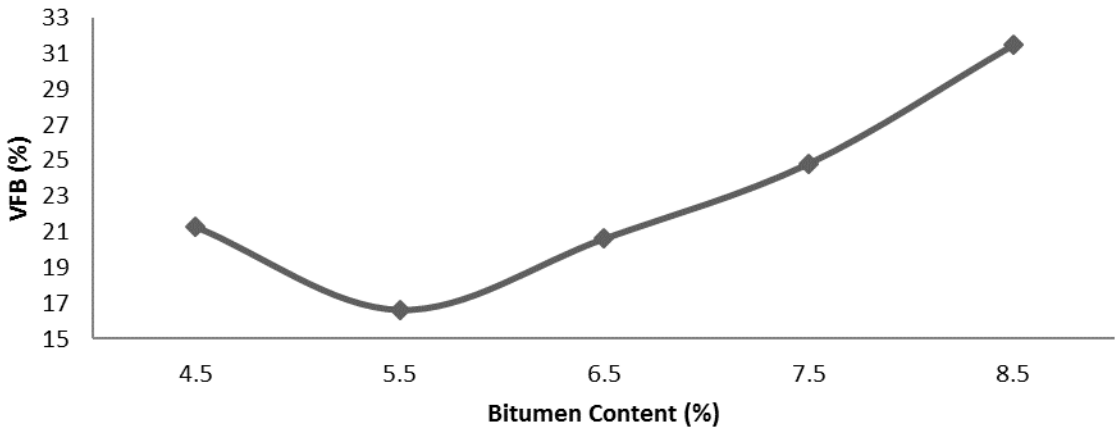

Figure 8: Graph of VFB against Bitumen Content

The voids filled with bitumen continuously increased with an increase in bitumen content, with a maximum value of 31.45% at a bitumen content of 8.5%, as shown in figure 8.

4.5.1 Optimum Bitumen Content

From the above analysis, the optimum binder content was calculated to be 5.5%, which has been adopted for usage in subsequent analysis.

4.5.2 Determination of Optimum RHA Percentage

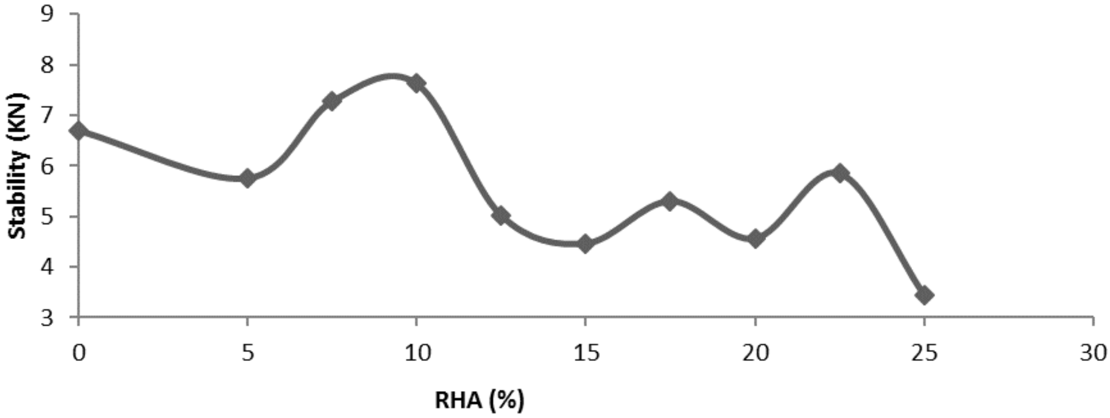

Figure 9: Graph of Stability against Percentage RHA at 5.5% Bitumen Content

From figure 9, the obtained stability is maximum at 10% RHA, with an optimum value of 7630N which is greater than the minimum stability specified according to ASTM D 1559, shown in Table 10. It is also observed that at 0% RHA (i.e. 100% Ordinary Portland Cement), the stability is 6700N which is also above the minimum specification.

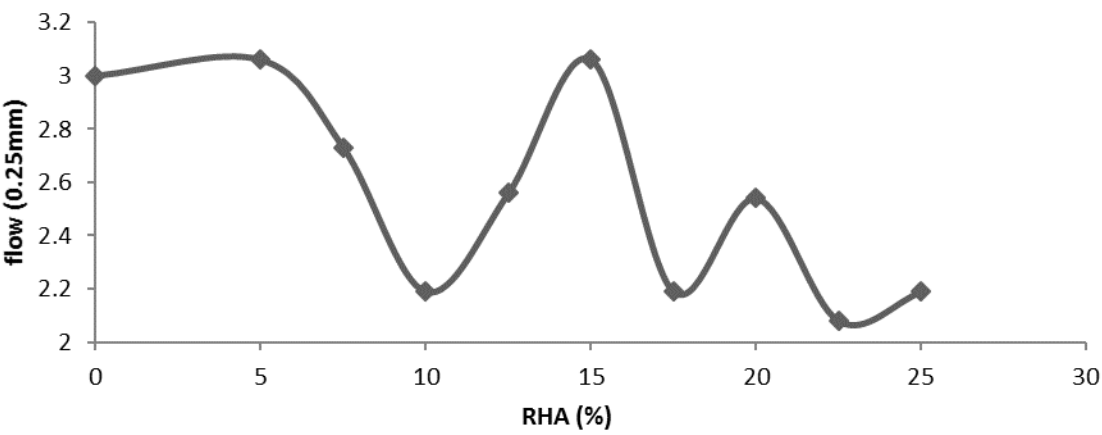

Figure 10: Graph of Flow against Percentage RHA at 5.5% Bitumen Content

From figure 10, the maximum flow was obtained at 15% RHA to be 3.06 (12.24mm), and the minimum flow at 22.5% RHA to be 2.08 (8.32mm) which falls between 2-14mm specification for heavy traffic according to Table 10.

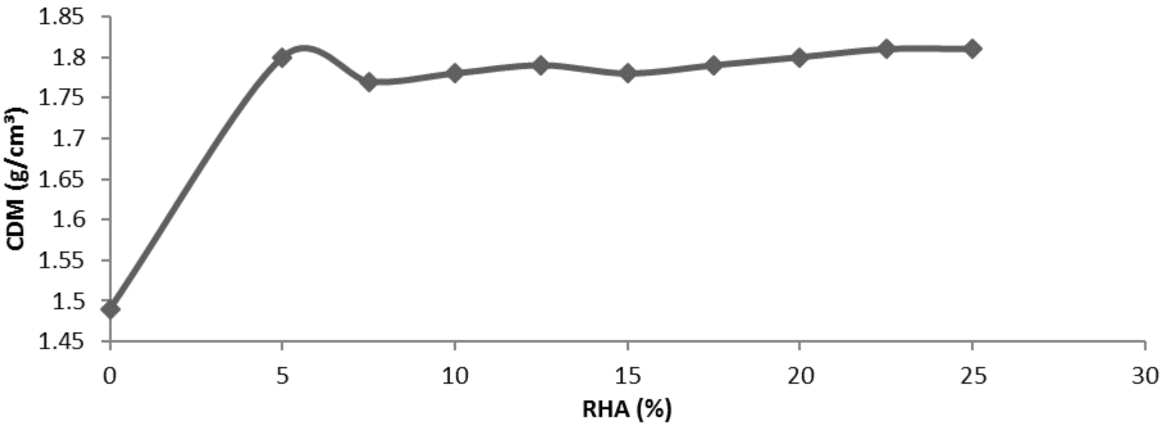

Figure 11: Graph of CDM against Percentage RHA At 5.5% Bitumen Content

From figure 11 above, the compacted density of the mix (CDM) was observed to be maximum at 22.5% RHA with a value of 1.81, and minimum at 7.5% RHA with a value of 1.77. It was also observed that at 0% RHA (i.e. 100% Ordinary Portland cement), a minimum CDM value of 1.49g/cm³ was obtained.

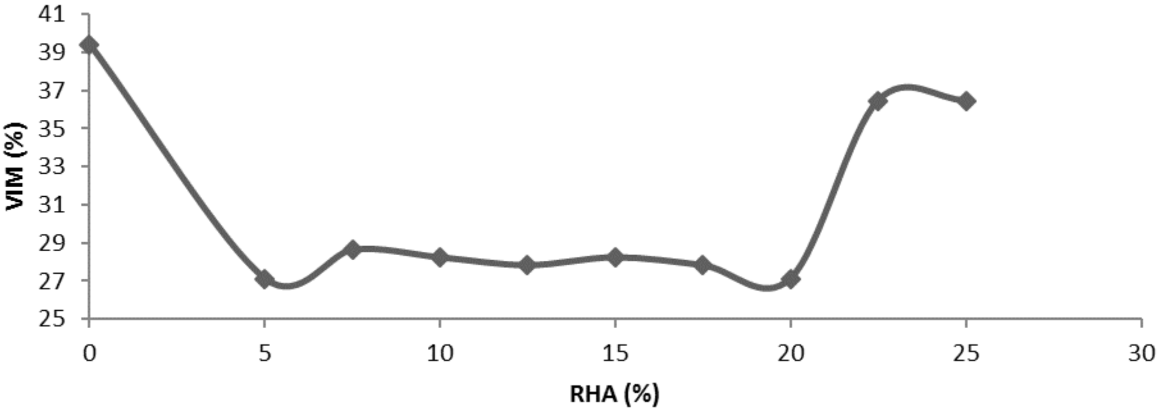

Figure 12: Graph of VIM against Percentage RHA At 5.5% Bitumen Content

From figure 12 above, the percentage void in mix (VIM) was observed to be maximum at 0%. It then continued to maintain a constant range of values of 27-28% with increase in RHA; it then increases to a value of 36.46% at 22.25% RHA.

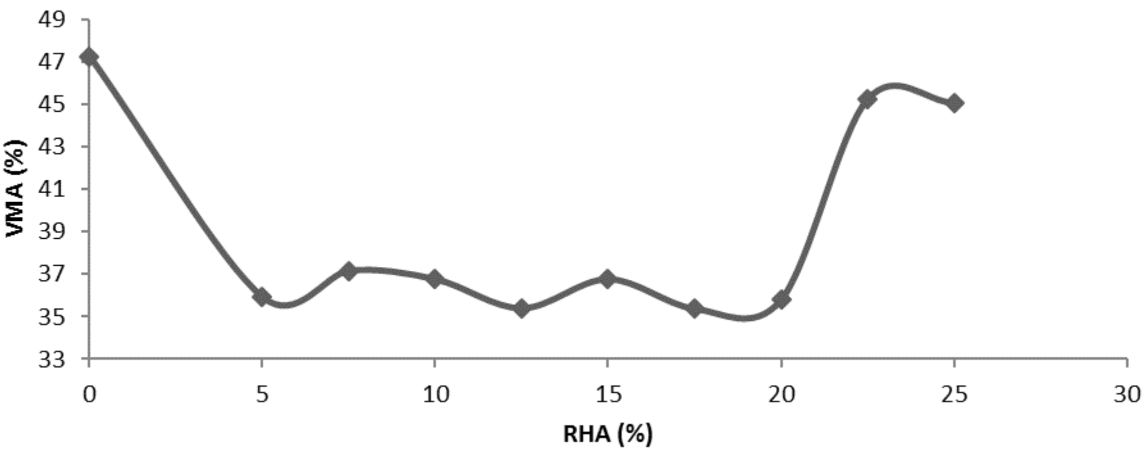

Figure 13 Graph of VMA against Percentage RHA At 5.5% Bitumen Content

As observed in figure 13, the void in mineral aggregate (VMA) continues to maintain a steady range of values of 35-37%. It then increases to a maximum value of 45.23% at 22.5% RHA. It was also observed that at 0% RHA, VMA had a value of 47.27%, which is more than that obtained at optimum RHA.

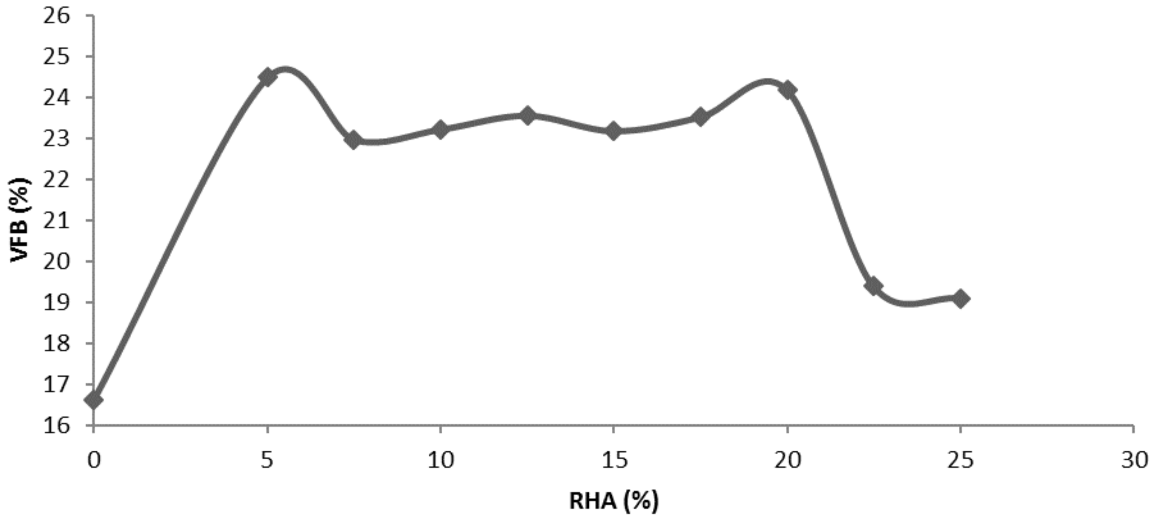

Figure 14: Graph of VFB (%) against Percentage RHA At 5.5% Bitumen Content

From figure 14, the voids from bitumen (VFB %) is steady with increase in percentage RHA values, with a constant value range of 22-24% it then decreases at 22.5% RHA to 19.39%. It was also observed that at 0% RHA, (VFB %) was minimum.

5. Conclusions and Recommendation

5.1 Conclusions

Based on the number of tests conducted, the following conclusions were reached;

- The constituents materials conform to the specified requirement therefore can be used in HMA.
- The RHA used in this research work is a pozzolana and conforms to the ASTM C618 requirement which has great potential use in concrete.
- The value for the required properties of bitumen as a binder as regards its penetration, viscosity, flash and fire point, durability and solubility all conform to those specified in ASTM standard specification of the design of asphalt concrete.
- The mix obtained using 10.0% RHA and 90% OPC meets the standard specified in terms of stability, flow, VIM, and VMA, at an optimum bitumen content of 5.5%.

5.2 Recommendation

In this study, one rice husk sample was used for the experiment. Future studies should use more than one sample from various sources. Mechanical properties such as tensile strength, flexural strength, and elastic modulus should be investigated in future research, as this will widen the application of RHA in asphalt concrete.

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