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Evaluating the performance of Asphalt concrete Using Chikoko as Mineral Filler

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Abstract: This paper presents a study on the laboratory evaluation of Asphaltic concrete using the Nigeria Deltaic clay (locally known as Chikoko) as an admixture. The Marshall Mix design procedure was employed in this study and the Optimum Bitumen content (OBC) was determined as 5.20%. The fine aggregate was replaced systematically with chikoko at 2%, 4%, 6%, 8% and 10% respectively, by weight of fine aggregate. The physical properties of the modified HMA were determined using the Marshall Test procedure. From the results obtained, the optimum result of chikoko usage as mineral filler in HMA was noticed at 6% replacement of chikoko by weight of fine aggregate. Therefore, the deltaic clay, chikoko, can be used effectively as mineral filler in HMA up to 6% replacement by weight of fine aggregate.

Keywords: Chikoko, Mineral Filler, Asphalt Concrete

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I. INTRODUCTION

In Nigeria, the provision of good roads at affordable rate have been difficult over the years due to the high and rising cost of construction materials. The total cost of road construction depends on the proportion and qualities of the component materials in the Asphalt mix. Asphalt mix is the combination of bitumen, coarse and fine aggregates and fillers mixed in a predetermined proportion to achieve a particular strength. There is therefore an immediate need of finding ways to reducing cost involved in the road construction process without negatively affecting the quality and the strength properties of the Hot Mix Asphalt Concrete.

Nigeria is a nation blessed with abundance of local construction materials such as stones, sand, laterite, marine clay etc. The potentials of these natural construction materials have not been fully exploited and utilized in the construction industry despite the positive result from some researchesinvolving some of these local construction materials. Marine clay otherwise known as chikoko, if properly treated and processed is one such local material that can be exploited for usage in the road construction industry.

Various researches have been carried out on improvement of asphalt concrete mix for the purpose of enhancing its effectiveness possibly by altering the constituents of the mixture in order to get changes on the positive side of the conventional mix. Mineral ingredients have been used as fillers to improve the asphalt as studies have shown that mineral ingredients play an important role in enhancing the performance of HMA. Numerous studies have been carried out to incorporate waste materials in HMA. These include (but not limited to scrap rubber, waste glass, boiler ash, incinerator residue, coal-plant refuse (Kandhal, 1992), steel slag (Huang et al., 2007). HMA is modified either through the coarse aggregate, fine aggregate, binder or mineral filler.

Minerals fillers are particles that pass sieve No. 200 (75µm). It is either mixed into the binder before mixing with aggregate (wet process) or incorporated into the mixture as part of aggregate (dry process). Anderson (1970) investigated the effects of eight different filler materials on mechanical properties of HMA and discovered that different filler materials have different effects on stiffness but almost no effect on Marshall Stability or Void ratio. Asi and Assa’ad (2005), from replacing 10% of conventional stone dust with Jordanian oil shale fly ash discovered that asphalt concrete mixes provided the best improvement in mechanical properties of the mix. Sharma et al., (2010) concluded that bituminous mixtures made using fly ash as mineral filler showed better properties than those made with stone dust filler.

Chikoko (marine clay) has been identified as a pozzolanic substance due to its chemical properties (presence of high amount of silica and alumina compounds) [Tangchirapat at al., 2006; Borhan at al., 2010). Chikoko from two separate locations are least likely to have different Engineering properties (Abdullah et al., 2006). Chikoko has proven to be an adequate material for partial replacement of OPC in concrete (Tannayopas et al., 2009). Chikoko usage in HMA has been studied by researchers such as Borhan et al. (2010) who found out that replacing 5% of fillers content with chikoko does not impair performance properties of asphalt concrete mix. He further found out that better stability values were obtained. Kamaluddi (2008) found that replacing stone dust with 100% chikoko resulted in the highest improvement in the stability and stiffness values. Wokoma

(2004)from his studies, reported that mixing of 85% chikoko plus 14.6% of quarry dust met the specification requirement for base and sub-base materials and concluded that chikoko can adequately be stabilized by blending with quarry dust. Eme (2006) from his study showed that the strength of chikoko after stabilization did not meet up the road specification of base and sub-base.

II. MATERIALS APPARATUS AND METHOD

2.1 Materials

The materials used in this study were:

i. The asphalt binder (bitumen) used, was sourced from a local market in Port Harcourt, Rivers State.
ii. The coarse and fine aggregate were sourced from a construction site in Port Harcourt. The sourced aggregates were washed and dried. The coarse aggregate is crushed stone. The fine aggregate is that portion finer than 4.75mm sieve.
iii. The chikoko (marine clay) was sourced from a swamp in Rumuoparali, Port Harcourt at depth less than 1m below top soil. The collected sample was separately sieved and portion finer than sieve No. 200 (75µm) obtained.

i. Equipment and Apparatus

The equipment and apparatus used here are outlined below;

ii. Marshall test machine for the determination of stability and flow of modified asphalt specimen
iii. Thermometer for temperature measurement in heated and cooled asphalt specimen.
iv. Sensitive balance for weight determination of specimens.
v. Other apparatus, include, flame source, sets of tag sieve, hand brush, scoop, pan etc.

2.3 Methodology

2.3.1 Experimental Design

The medium traffic category was adopted for the experimental set up involved in this research. The aggregate were subjected to sieve analysis in order to obtain the right mix proportion for design using the straight line method of aggregate blending, the right mix proportion was obtained after three trials. The optimum Bitumen content was determined using the marshal mix design procedure. The fine aggregate portion of the optimum mix design was then partially replaced by the mineral filler (chikoko) at 2-10% with 2% increment by weight of fine aggregates. Laboratory tests were carried out to determine the physical and mechanical properties of the modified Asphalt concrete.The physical properties of concern here are; specific gravity, percentage Air voids in mineral aggregate (VMA), voids filled with bitumen (VFB). The Marshall stability and flow tests were adopted in determination of stability and flow of modified asphalt concrete.

2.3.2 Optimum Aggregate Mix Blend

The aggregate involved here were properly combine using the straight line approach to meet gradation specification. This was possible after subjecting the aggregate to sieve analysis. The optimum combination obtained after the gradation test is as shown in Table 1.

Table 1. Optimum Aggregate Combination

Sieve(mm)	40	20	10	4.75	2.36	0.600	0.075
A * 0.60	60	58.20	40.20	10.20	7.20	3.60	0.60
B * 0.40	40	40	39.60	39.20	37.20	22.40	0.40
Total	100	98.20	79.80	49.40	44.40	26.0	1.00
Specification	100	80-100	55-80	40-60	30-60	15-30	0-10

The optimum aggregate blend is seen to properly fit into the specification limit (Figure 1).

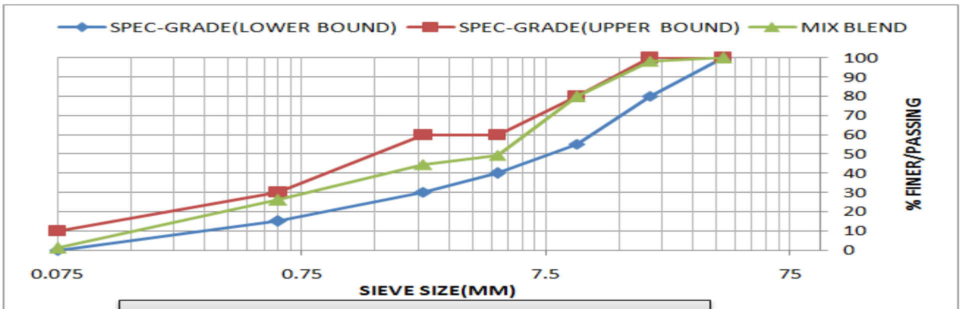

FIG. 1. AGGREGATE GRADATION CURVE

2.3.3 Optimum Asphalt Content

The optimum binder/asphalt/Bitumen content was determined using the marshal test procedure. Three sets of unmodified asphalt concrete per experiment were subjected to experimental analysis with the bitumen content at 4%, 4.5%, 5%, 5.5%, and 6% respectively.

These samples were subjected to stability and flow tests, percentage air voids tests and density tests. The Optimum Bitumen Content (OBC) was obtained in accordance to Equation 1. Table 2 shows the design mix for unmodified HMA in determination of Optimum Bitumen Content and Figure 2 (a-e) presents the result for OBC determination.

Table 2. Mix Ratio for obtaining OBC for Unmodified HMA

% Bitumen Content	Bitumen Weight(g)	Aggregate Weight(g)	% Blend of Aggregates(g)	
4%	48	1151	A(60%)	691.2
			B(40%)	460.8
4.5%	54	1146	A(60%)	687.6
			B(40%)	458.4
5%	60	1140	A(60%)	684.0
			B(40%)	456.0
5.5%	66	1134	A(60%)	680.4
			B(40%)	453.6
6%	72	1128	A(60%)	676.8
			B(40%)	451.2

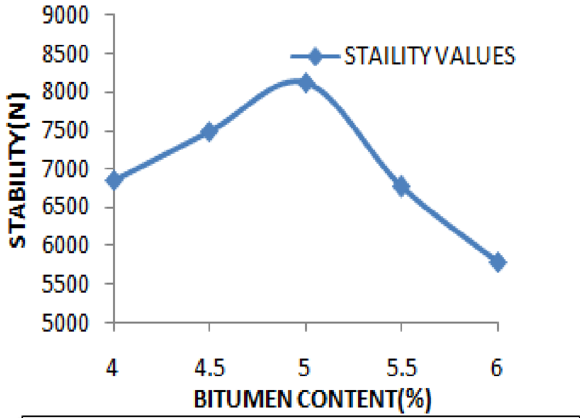

FIG.2a. STABILITY VALUES VS PERCENTAGE BITUMEN CONTENT

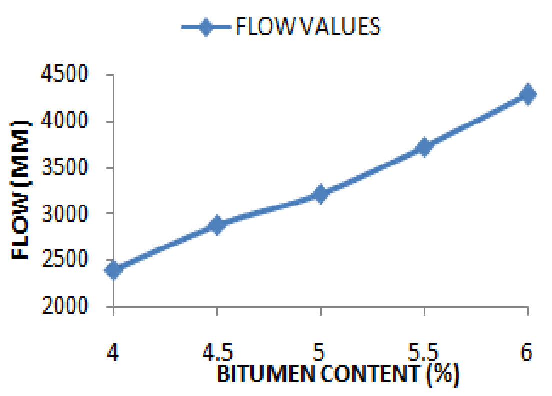

FIG.2b. FLOW VALUES VS PERCENTAGE BITUMEN CONTENT

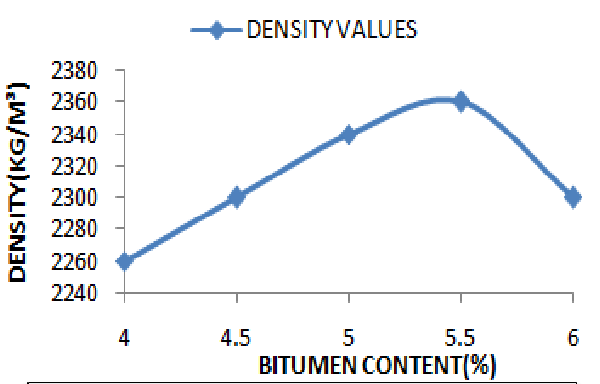

FIG.2C. DENSITY VALUES VS PERCENTAGE BITUMEN CONTENT

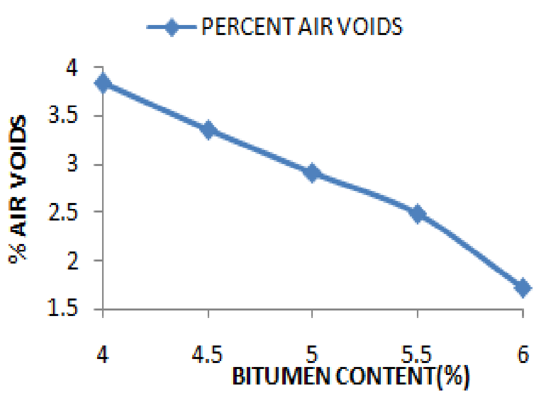

FIG.2d. PERCENT AIR VOID VS PERCENT BITUMEN CONTENT

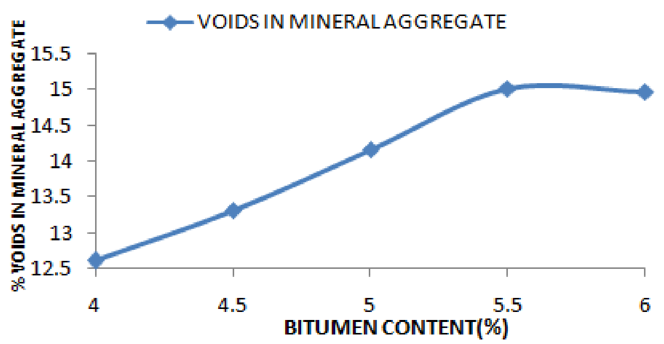

FIG. 2e. VMA VS PERCENT BITUMEN CONTENT

Optimum Bitumen Content $= \frac{A+B+C}{3}$ (1)

Where; A = Asphalt maximum content at stability value
B = Bitumen content at maximum density value
C = Asphalt content at median limits of air voids

2.3.4 Sample Preparation

The proportioned aggregates were heated to elevated temperature above 160^{0}C. The sourced bitumen was also heated to temperature of 120^{0}C - 145^{0}C for both mixes. The heated aggregate and bitumen were mixed together at a temperature over 165^{0}C in a mould. The top surface was leveled and covered with compacting papers. The chikoko was also heated and added in partial proportions to the Hot Mix Asphalt and then subjected to laboratory tests and analysis.

1.3.5 Physical Properties of Modified Asphalt Concrete

a. Specific Gravity (G_M)

The specific gravity of modified specimens were determined through the volumetric test. The test was performed in accordance to ASTM D6927. The specific gravity was thus calculated using Equation 2

$G_M = \frac{Wa}{Wa-Ww}$ (2)

Where: Wa = Weight of Modified Specimen in Air
Ww = Weight of Modified Specimen in water

b. Percentage Air Voids, Va

The percentage air void present in the modified sample was determined according to Equation 3

$V_a = \left(\frac{Gt-Gm}{Gt}\right) \times 100$ (3)

Where: Gt = Theoretical Specific Gravity
Gm = Specific Gravity

c. Voids in Mineral Aggregate, VMA

The VMA was calculated according to Equation 4.

$VMA = V_{ai} + V_b$ (4)

Where; V_{ai} = percentage air voids at chikoko content of 1%
V_b = Percentage bitumen content = 11.75%

d. Voids Filled with Bitumen VFB

The voids occupied by bitumen as the modified content increases was calculated using Equation (5)

$VFB = \frac{V_b \times 100}{VMA}$ (5)

2.3.6 Marshall Stability and Flow Tests

The stability and flow values of the modified specimen were determined with the aid of the marshal apparatus according to ASTM (2006). The stability portion of the test machine measures the maximum load supported by the test specimens at a loading rate of 50mm/minute. The load is increased until a maximum value was reached. This maximum load was recorded.

During loading, an attached dial gauge measures the specimen's plastic flow as a resultof the loading. The flow value was measured in 0.25mm increments at the same time the maximum load was recorded.

III. RESULTS AND DISCUSSIONS

3.1 Results

The results of the physical tests, stability flow tests conducted are presented and discussed in this section.

3.1.1 Physical Tests Result

The results for the specific gravity, percentage Air voids, voids in mineral aggregate, voids filled with Bitumen are presented in Table 3

Table 3. Physical Tests Results

% Chikoko	Specific Gravity, G_m	Theoretical Specific Gravity, G_t	% Air Voids, Va	Voids in Mineral Agg, VMA	VFB
2	2.37	2.44	2.82	14.45	80.65
4	2.47	2.54	2.70	14.57	81.32
6	2.52	2.58	2.45	14.20	82.75
8	2.45	2.51	2.18	13.93	84.35
10	2.38	2.42	1.82	13.90	84.53

Figure 3 (a-d) represents clearly the relationship between the percentage concentrations of chikoko with the obtained physical properties values.

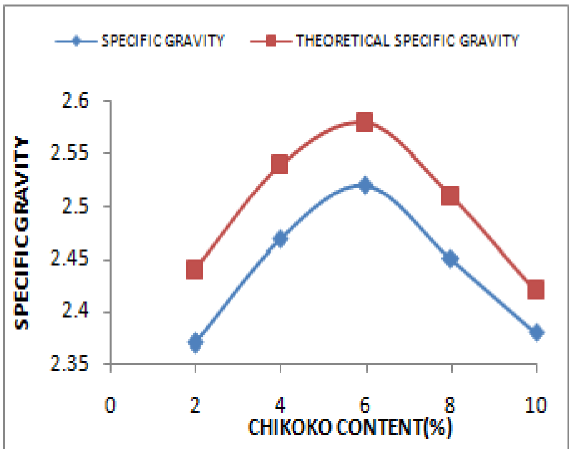

FIG.3a. SPECIFIC GRAVITY VS MODIFIER CONTENT

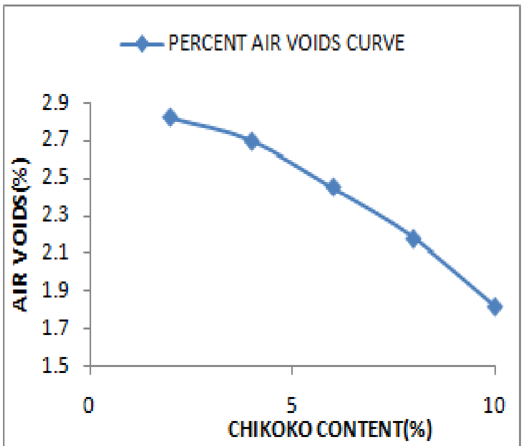

FIG.3b. PERCENT AIR VOIDS VS MODIFIER CONTENT

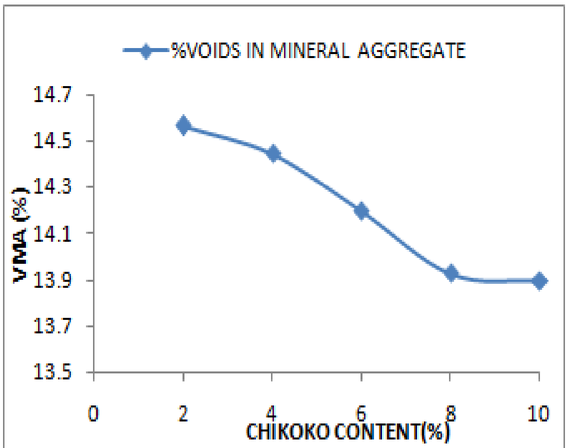

FIG.3c. PERCENT VMA VS MODIFIER CONTENT

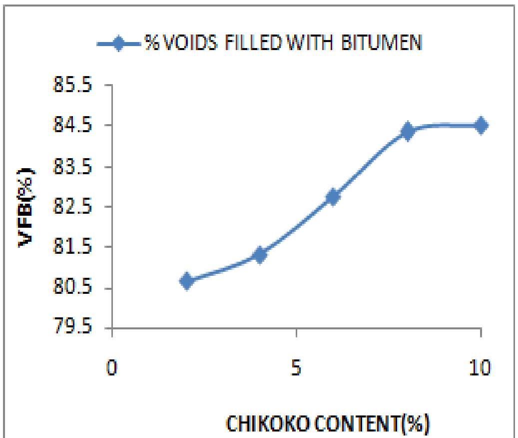

FIG.3d. PERCENT VFB VS MODIFIER CONTENT

3.1.2 Stability and Flow Tests Result

The result obtained from the marshal stability and flow test are presented in Table 4

% Chikoko	Density (kg/m^3 1000 (Gm)	Stability (N)				Flow Value (mm)			
		(1)	(2)	(3)	AV	(1)	(2)	(3)	AV
2	2370	8200	7940	8100	8080	3400	3380	3408	3396
4	2470	8120	8260	8145	8175	3420	3415	3245	3360
6	2520	8430	8175	8310	8305	3430	3280	3346	3352
8	2450	8340	8280	8205	8375	3510	3290	3241	3347
10	2380	8215	8120	7941	8095	3410	3090	3454	3318

The result in Table 4 are represented in Figures 4, 5 and 6

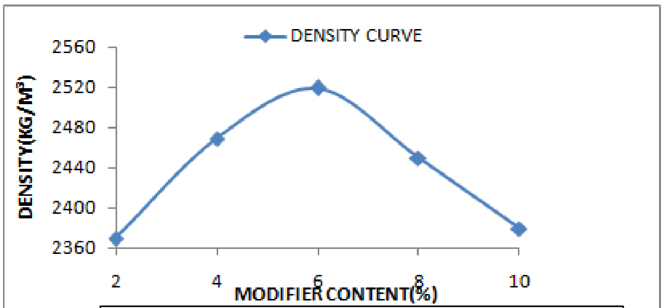

FIG.4. DENSITY VS PERCENT MODIFIER CONTENT

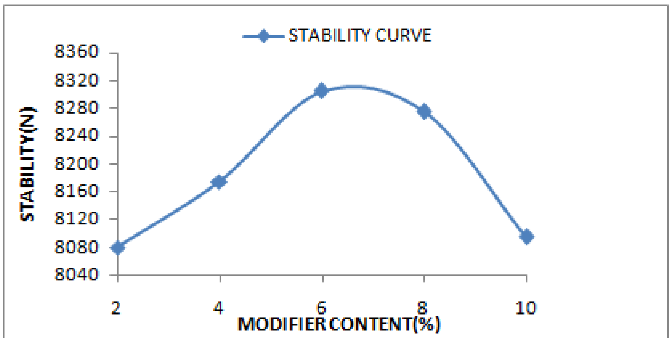

FIG.5. STABILITY VS PERCENT MODIFIER CONTENT

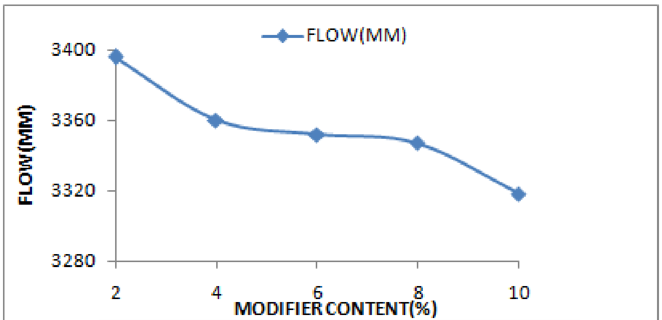

FIG.6. FLOW VS PERCENT MODIFIER CONTENT

3.2 Modeling the Properties of Modified HMA concrete

The models for stability and flow values adopted here assume the second degree polynomial of the form of Equation 6.

$Y = C_1 + C_2x + C_3x^2$ (6)

Where; C_1, C_2 and C_3 = coefficients of polynomial equation

Y = Predicted HMA concrete property value.

Given n sets of measurement, Equation (6) can be transformed to Equations (7) to (9) using the least square estimates.

$$\Sigma y = C_3^{\Sigma} x^2 + C_2 \Sigma x + C_1 n \quad (7)$$

$$\Sigma xy = C_3 x^3 + C_2 \Sigma x^2 + C_1 \Sigma x \quad (8)$$

$$\Sigma x^2 y = C_3 \Sigma x^4 + C_2 \Sigma x^3 + C_1 \Sigma x^2 \quad (9)$$

3.2.1Stability Model

In deducing stability model, Table 5 was produced in order to determine the model coefficients.

Table 5. Determination of Stability Model Coefficients

x	y	x^2	x^3	x^4	xy	x^2y
2	8080	4	8	16	16160	32320
4	8175	16	64	256	32700	130800
6	8305	36	216	1296	49830	298980
8	8275	64	512	4096	66200	529600
10	8095	100	1000	10,000	80950	809500
$\Sigma x = 30$	$\Sigma y = 40930$	$\Sigma x^2 = 220$	$\Sigma x^3 = 1800$	$\Sigma x^4 = 15664$	$\Sigma xy = 245840$	$\Sigma x^2 y = 1801200$

Substituting into Equations (7) – (9) we have

$$40930 = 220C_3 + 30C_2 + 5C_1$$

$$245840 = 1800C_3 + 220C_2 + 30C_1$$

$$1801200 = 15664C_3 + 1800C_2 + 220C_1$$

Solving simultaneously gives

$$C_3 = -12.68; \;\; C_2 = 158.64; \;\; C_1 = 7792$$

Thus, Polynomial becomes; as shown on equation

$$Y_S = 7792 + 158.64x - 12.68x^2. \; (10)$$

3.2.2. Flow Model

Following the same algorithm as for the stability model. The modelfor flow property of modified HMA concrete as given by Equation (11).

$$Y_F = 3414 - 12.09x + 0.30x^2 (11)$$

3.3 Validation of Models

The stability and flow model developed were subjected to the R-square statistics procedure for validation. The R^2 values were determined, using Equation (12)

$$R^2 = \frac{\Sigma(y_{est} - \overline{y})}{\Sigma(y - \overline{y})^2} (12)$$

Where ; y_{est} = Predicted property value of modified HMA
Y = Experimental or actual property value
$\overline{y}$ = Average experimental property value

The R^2 values for stability and flow models were obtained as 0.90 and 0.92 respectively.

The models developed above can adequately predict the stability and flow of values of modified HMA as adopted by the high coefficient of determination (R^2 values)

3.4 Discussion

From the physical properties, stability and flow values of the modified HMA concrete with chikoko (marine clay) showed good improvement.

The air voids present in the unmodified HMA reduce as the concentration of the chikoko increases (Figure 3c).This increment is beneficial to a certain percentage of modification. Adequate voids in the total compacted mixture are necessary to permit small amount of compaction when traffic load is applied without bleeding.

The voids filled with Bitumen (VFB), increases as the modifier content increases (Figure 3e). This indicates improvement in the resistance against binder age.

From Figure 4, the density of modified HMA concrete increases as modifier content increases to the 6% modifier concentration after which the density decreases. This indicates strength increment of HMA to the 6% chikoko addition.

The increase in chikoko concentration in the HMA also has positive effect on the stability of HMA to the 6% chikoko concentration (Figure 5). This helps to prevent unacceptable distortion and displacement when traffic load is applied.

The flow value reduces as the chikoko content increases (Figure 6). This is also a positive result to some percentage of modification ensuring adequate workability to facilitate placement of mix without segregation.

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

From results and discussions of the study the following conclusions are made.

i. The optimum concentration of chikoko as mineral filler is 6%. Therefore, the addition of chikoko as a mineral filler should not exceed this percentage.
ii. The density, which signifies the strength of HMA increases as the modifier concentration increases to the 6% concentration.
iii. The air voids present in the unmodified HMA reduces as the concentration of chikoko increases.
iv. The stability of HMA concrete increases as chikoko content increases to the 6% concentration.
v. The flow values of modified HMA reduces as modifier content increases.

4.2 Recommendations

The medium traffic category was used as the reference point in this study. Further studies should be done for other traffic category consideration.

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