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Prediction of Stability and Flow Properties of Hot Mix Asphalt Using Cement as a Filler Material

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Abstract: *This paper was aimed at developing mathematical models for the prediction of stability and flow properties of Hot Mix Asphalt with cement as the filler material. The Scheffe's simplex lattice theory was used in the development of the mix design and optimization models of the stability and flow properties. For a four component mixture, the (4, 2) simplex lattice was used with the four (4) representing the number of constituent material and the two (2) representing the degree of assumed polynomial. The developed models were subjected to validity tests using the F-Statistics. From the analysis of results, the mathematical models developed proved adequate at 5% level of significance and can be relied upon in the prediction/optimization of the properties of HMA.*

Keywords;*Scheffe's simplex lattice, Stability, Flow, HMA, Marshal mix design*

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I. Introduction

Hot mix asphalt (HMA) pavements are being increasingly constructed in developing countries such as Nigeria. Flexible pavements are made up of a wearing course, which is an asphalt concrete mix, a base course (usually crushed stone), and a sub-base course (usually river sand or laterite) on the natural sub-grade. The design of flexible pavements in these developing countries have usually followed the conventional method of design which is in two stages [1]: the dry mix design and the wet mix design. In various developed countries, researches have been conducted to produce mixes with improved properties by altering the HMA constituting ingredients. Thus, in the HMA mix design process, care must be exercised while selecting the type of ingredient materials and their relative proportion in the mixture. In the dry mix design stage, a dense mixture may be obtained when particle size distribution follows Equation (1)[2].

$$p = 100\left(\frac{d}{D}\right)^n \tag{1}$$

Where; p = total percentage passing a given sieve, d = size of sieve opening
D = maximum size of aggregate, n = grading exponent.

In the wet mix design stage, the Marshal mix design, the Hveem mix design or the Superpave design procedure can be adopted with the Marshal mix design being the commonest design procedure employed in developing countries such as Nigeria. The major shortcoming of the conventional method of design sterns from the fact that the optimum mix design is produced without any model relating the HMA property and the mixture proportions, hence, every design would require new sets of experiments.

In order to take care of this situation, the Scheffe's simplex lattice theory of mixtures which has proven to be a success in the concrete and building industry was employed in this study to relate the stability and flow properties of HMA to the components proportions. The optimum or best mix design to be used in HMA can be obtained through optimization processes. Optimization is the process of obtaining the maximum or minimum value of a quantity and in turn satisfying a range of desired requirements of the quantity [3]. The concept of optimization eliminates the stress associated with conducting increased number of experimental runs needed to obtain the desired response parameter with same level of accuracy when compared with that obtained in an optimal design. [4], formulated models for the prediction of the compressive strength of lateritic concrete using the Scheffe's Theory. [5]also optimized the strength of cement-lateritic-sand hollow sandcrete blocks using the Scheffe's optimization procedure. [6]developed an optimization model to predict the compressive strength of cassava peel ash blended cement sandcreteblocksusingScheffe's second degree polynomial. [7]applied the Scheffe's theory to optimize the compressive strength of lateritic concrete. [8]developed a mathematical prediction model to predict the resilient modulus for natural soil stabilized by POFA-OPC additive for the use in unpaved road design using the Scheffe optimization procedure.

Although the Scheffe's technique has not been used previously in the prediction/optimization of the properties of HMA, but with HMA being a composite material of; aggregates (coarse and fine), bitumen and filler, the Scheffe's theory of mixtures can be applied in the prediction/optimization of HMA properties such as stability and flow. Estimating the Marshall stability of different HMA samples based on multiple mixes can be tedious and time-consuming. The Scheffe's procedure for design would reveal a mathematical model which can be used in the prediction/optimization of HMA properties.

II. Materials and Methods

2.1 Research Design

This research is directed towards predicting the stability and flow properties of asphaltic concrete using cement as a filler material using the Scheffe's procedure for design and model development. Four basic materials were used in this study; bitumen, coarse aggregate (of maximum size 12mm), fine aggregate and cement (as filler material). In mix design and model development, the Scheffe's (4,2) simplex procedure was adopted. All materials used in this study were sourced within the Port Harcourt City environment. Marshall Stability and flow tests were carried out on prepared asphalt concrete samples using appropriate experimental procedures. Models were developed for the prediction of the stability and flow properties of asphaltic concrete through the trial mixes produced and validated subsequently using the results from the trial mixes. These developed models were subjected to validity tests using appropriate statistical procedures.

2.2 Materials

Four materials; bitumen, coarse aggregate, fine aggregate and cement sourced from within the Port Harcourt City Environment were prepared and used in this study.

2.2.1. Bitumen

Bitumen of penetration grade 80/100 sourced from a reputable company within Port Harcourt was used in this study. This bitumen met the requirements to be used as asphaltic cement for a medium traffic category.

2.2.2. Coarse Aggregate

Granite of maximum size 12mm was used as coarse aggregate in this study for experimental purposes. This granite was obtained from a construction site in Port Harcourt. The sourced granite were subjected to sieve analysis in order to remove all unwanted materials and other organic matter.

2.2.3. Fine Aggregate

Fine river sand sourced from a sand fill location in Port Harcourt was used for the purpose of experiment in this study. The sourced river sand was sun-dried for about seven (7) days to remove every trace of moisture and then properly sieved using 4.5mm sieve to remove all unwanted materials.

2.2.4. Cement

The Dangote Brand of Portland cement (R. 425, CB 4227) in accordance with the requirements of [9] was used for this study. The cement was sourced from a local shop in Port Harcourt, Rivers State.

2.3 Methodology

2.3.1 Experimental Design Matrix Formulation

Scheffe[10] uses the simplex lattice concept in combining mixture components. Jackson [11] defined a simplex as a structural representation (shapes) of lines or planes joining assumed points of constituent materials of a mixture and which such points are equidistant from each other. According to Scheffe [10], a (q, m) mixture, with q being the number of component materials and m being the maximum number of component interactions, has number of points given as;

$$N = \frac{(q + m - 1)!}{(q-1)!\,m!} \tag{2}$$

Where; q = number of components materials; m = maximum number of interactions

Application of Equation (2) for a (4, 2) component mixtures gave a value of 10 number of experimental points giving rise to the simplex lattice shown in Figure 1. The four component materials used in this study were; bitumen, coarse aggregate, fine aggregate, and cement as filler. The (4, 2) simplex lattice considered here is represented schematically by Figure 1.

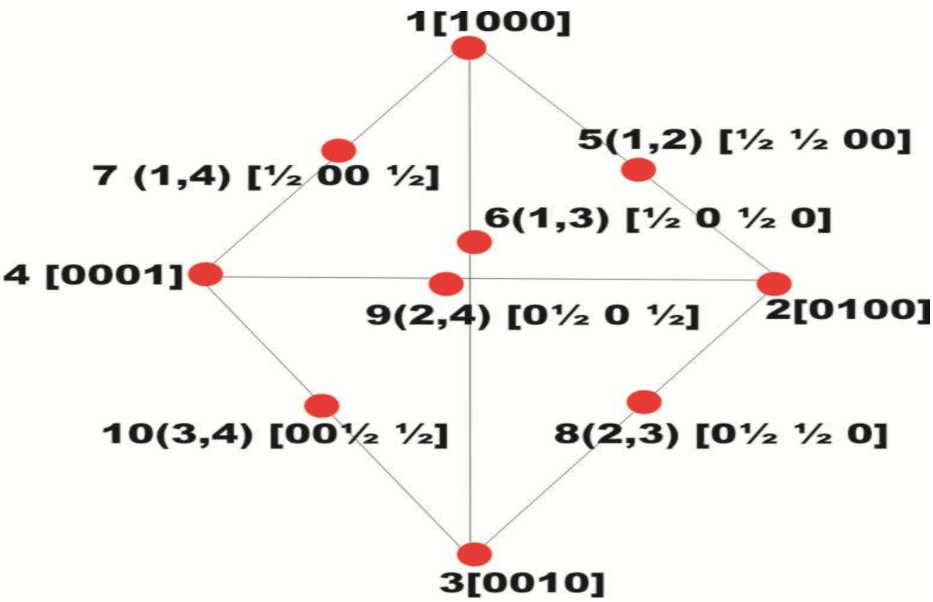

Figure 1: A (4, 2) simplex lattice adopted for this study

According to Scheffe, mixture proportions are being represented in pseudo (theoretical) mix ratios. Pure substance exist at the vertices points and the method rely on the condition that the summation of all pseudo mix ratios at any point must be equal to 1. Mathematically;

$$\sum_{i=1}^{q} x_i = 1 \qquad (3)$$

To achieve the condition of Equation (3), actual mix ratios must be converted to pseudo mix ratios. The relationship between pseudo and actual mix ratios is given by;

$$Z = [A]X \qquad (4)$$

Where:
Z = column matrix of real component ratio.
X = column matrix of pseudo component ratio.
[A]= coefficient matrix which is the transpose of the permutation matrix.

The permutation matrix was established from experience and intelligent guesses of HMA mixes. The bitumen content was assumed to be between 4-6% of total weight/volume of HMA, making the aggregate content to be limited to 94-96% of total mix. The coarse aggregate was limited to 50-65% of aggregate content thereby limiting fine aggregate content to 35-50% of aggregate content. The filler content was limited to the range of 4-7% of the fine aggregate content. For the vertices, where pure substances are assumed to exist, the mix ratios were obtained as; (1, 13.2, 10.37, 0.43), (1, 11.40, 7.22, 0.38), (1, 11.17, 5.65, 0.36) and (1, 7.83, 7.29, 0.55) for these points. In matrix form;

$$[P] = \; 1 \begin{bmatrix} 1 & 13.2 & 10.37 & 0.43 \\ 1 & 11.40 & 7.22 & 0.38 \\ 11.17 & 5.65 & 0.36 & \\ 1 & 7.83 & 7.29 & 0.55 \end{bmatrix} \qquad (5)$$

With the corresponding pseudo mix ratio being;

$$[X] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (6)$$

The transpose of matrix [P], becomes;

$$[A] = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 13.2 & 11.40 & 11.17 & 7.83 \\ 10.37 & 7.22 & 5.65 & 7.29 \\ 0.43 & 0.38 & 0.36 & 1.25 \end{bmatrix} \quad (7)$$

Making X subject of formula from Equation (4), yields Equation (8):

$$X = [A]^{-1}Z \quad (8)$$

Where: $[A]^{-1}$ = inverse of coefficient matrix.

These Equations were then used in formulating the mix design for this study. Table 1 and 2 gives the experimental mix design for this study using Scheffe's method of mixtures.

Table 1. Mix Design for trial mixes.

S/N	PSEUDO COMPONENTS RATIO				ACTUAL/ REAL COMPONENTS RATIO			
	X_1(Bitumen)	X_2(C.A)	X_3(F.A)	X_4(Cement)	Z_1(Bitumen)	Z_2(C.A)	Z_3(F.A)	Z_4(Cement)
1	1	0	0	0	1	13.2	10.37	0.43
2	0	1	0	0	1	11.40	7.22	0.38
3	0	0	1	0	1	11.17	5.65	0.36
4	0	0	0	1	1	7.83	7.29	0.55
5	0.5	0.5	0	0	1	12.30	8.795	0.405
6	0.5	0	0.5	0	1	12.19	8.01	0.395
7	0.5	0	0	0.5	1	10.50	8.83	0.49
8	0	0.5	0.5	0	1	11.285	6.435	0.37
9	0	0.5	0	0.5	1	9.615	7.255	0.465
10	0	0	0.5	0.5	1	9.50	6.47	0.455

Table 2. Mix Design for control mixes.

S/N	PSEUDO COMPONENTS RATIO				ACTUAL/ REAL COMPONENTS RATIO			
	X_1(Bitumen)	X_2(C.A)	X_3(F.A)	X_4(Cement)	Z_1(Bitumen)	Z_2(C.A)	Z_3(F.A)	Z_4(Cement)
1	0.25	0.25	0.25	0.25	1	10.9	7.633	0.43
2	0.20	0.20	0.30	0.30	1	10.62	7.40	0.435
3	0.30	0.30	0.20	0.20	1	11.18	7.865	0.425
4	0.20	0.20	0.20	0.40	1	10.286	7.564	0.454
5	0.10	0.30	0.30	0.30	1	10.44	7.085	0.43

2.3.2 Model Formulation and Coefficients Determination

Equation (9) gives the general polynomial format for a (q, m) polynomial, where q represents the number of variables and m represents the degree of the polynomial;

$$\underset{i\le 1\le q}{\overset{n}{Y}} = b_0 + \sum_{i\le 1\ge j\le q} b_i X_i + \sum_{1\le 1\le j\le q} b_{ij} X_j X_{ij} + \ldots\ldots\ldots + \sum b_{ijk} + \sum b_{i1i2\ldots\ldots\ldots} \; in \; X_{i1} X_{i2} \ldots\ldots \; X_{in} \quad (9)$$

Where; $1 \le i \le q$, $1 \le i \le j \le q$, $1 \le i \le j \le k \le q$, and b is the constant coefficient.
X is the pseudo component for constituents i , j , and k

For a (q, m) polynomial of second degree form with four (4) number variables, Equations (3) and (9) become;

$$X_1 + X_2 + X_3 + X_4 = 1 \quad (10)$$

$$\tilde{Y} = b_0 + b_1X_1 + b_2X_2 + b_3 X_3 + b_4 X_4 + b_{12}X_{12}X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{24}X_2X_4 + b_{23}X_2X_3 + b_{34}X_3X_4 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 \quad (11)$$

Multiplying through Equation (10) by constant b_0, yields Equation (12).

$$b_0X_1 + b_0X_2 + b_0X_3 + b_0X_4 = b_0 \quad (12)$$

Again, multiplying Equation (10) by X_1, X_2, X_3, and X_4 in succession and rearranging, Equation (13) is produced.

$$\left.\begin{aligned} X_1^2 &= X_1 - X_1X_2 - X_1X_3 - X_1X_4 \\ X_2^2 &= X_2 - X_1X_2 - X_2X_3 - X_2X_4 \\ X_3^2 &= X_3 - X_1X_3 - X_2X_3 - X_3X_4 \\ X_4^2 &= X_4 - X_1X_4 - X_2X_4 - X_3X_4 \end{aligned}\right\} \quad (13)$$

Substituting Equations (12) and (13) into Equation (11), we obtain Equation (14) after necessary transformation.

$$\tilde{Y} = (b_0 + b_1 + b_{11})\ X_1 + (b_0 + b_2 + b_{22})\ X_2 + (b_0 + b_3 + b_{33})\ X_3 + (b_0 + b_4 + b_{44})\ X_4 + (b_{12} - b_{11} - b_{22}) X_1X_2 + (b_{13} - b_{11} - b_{33}) X_1X_3 + (b_{14} - b_{11} - b_{44}) X_1X_4 + (b_{23} - b_{22} - b_{33}) X_2X_3 + (b_{24} - b_{22} - b_{44}) X_2X_4 + (b_{34} - b_{33} - b_{44}) X_3X_4 \quad (14)$$

Denoting; $B_i = b_0 + b_1 + b_{11}$ and
$B_{ij} = b_{ij} - b_{ii} - b_{jj}$

The reduced second degree polynomial in 4 variables is shown by Equation (15).

$$\tilde{Y} = B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_{12}X_1X_3 + B_{13}X_1X_3 + B_{14}X_1X_4 + B_{23}X_2X_3 + B_{24}X_2X_4 + B_{34}X_3X_4 \quad (15)$$

The number of coefficients has reduced from 15 in Equation (11) to 10 in Equation (15). Thus, the reduced second degree polynomial in q-variables is as shown by Equation (16).

$$\tilde{Y} = \sum_{1 \le i \le q} B_i X_i + \sum_{1 \le i \le q} B_{ij} X_i X_j \quad (16)$$

At the vertices of Figure 1, pure substances are signified [10]. At any vertex, only one component of the mixture is represented while at boundary lines two components exist and the others are absent. Thus, the points 1, 2, 3 and 4 were presented as having these coordinates; [1, 0, 0, 0], [0, 1, 0, 0], [0, 0, 1, 0] and [0, 0, 0, 1]. Substituting the first four lattice coordinates into Equation (15) yields Equation (17)

$$\left.\begin{aligned} Y_1 &= B_1 \\ Y_2 &= B_2 \\ Y_3 &= B_3 \\ Y_4 &= B_4 \end{aligned}\right\} \quad (17)$$

From Figure 1, Point 5 with coordinate [½, ½, 0, 0], Equation (18) can be deduced;

$$\begin{aligned} Y_{12} &= \tfrac{1}{2} X_1 + \tfrac{1}{2} X_2 + \tfrac{1}{4} X_1X_2 \quad (18) \\ &= \tfrac{1}{2}B_1 + \tfrac{1}{2}B_2 + \tfrac{1}{4}B_{12} \end{aligned}$$

$B_i = Y_i$, where i = 1, 2, 3,……..n. Then substituting into Equation (15) yields:

$$Y_{12} = (\tfrac{1}{2})Y_1 + (\tfrac{1}{2})Y_2 + (\tfrac{1}{4})\ B_{12} \quad (19)$$

Simplifying Equation (19), yields:

$$B_{12} = 4Y_{12} - 2Y_1 - 2Y_2 \quad (20)$$

Similarly, Equation (21) to Equation (23) can be developed. Thus:

$$B_{13} = 4Y_{13} - 2Y_1 - 2Y_3 \quad (21)$$

$$B_{14} = 4Y_{14} - 2Y_1 - 2Y_4 \quad (22)$$

$$B_{23} = 4Y_{23} - 2Y_2 - 2Y_3 \quad (23)$$

Generalizing, Equations (20) to (23), Equation (24) was formed.

$$\left.\begin{aligned} B_i &= Y_i \\ B_{ij} &= 4Y_{ij} - 2Y_i - 2Y_j \end{aligned}\right\} \quad (24)$$

The above values become the coefficients of the (4, 2) second degree polynomial in Equation (15).

2.3.3. Model Validation

Models developed were subjected to Fisher test (F-test) for validation and adequacy check. The F-statistics is given as the ratio of variance between the predicted/model response value and that of experimental value. The following hypothesis were adopted in validation of models;

Null Hypothesis: H_0 = there is no significant difference between the experimental and predicted responses.

Alternate Hypothesis: H_1= there is a significant difference between the experimental and predicted responses.

Mathematically, the F-test is represented by Equation (25).

$$F = \frac{S_1^2}{S_2^2} \quad (25)$$

Where; S_1^2 = Larger of both variances

S_2^2 = Smaller of both variance

S^2 is obtained from Equation (26)

$$S^2 = \frac{1}{n-1}\left[\sum (Y - \bar{Y})^2\right] \quad (26)$$

Where : $\overline{Y}$= Average mean of response, Y
Y = Means of response
The models developed were declared adequate if the F-value calculated in accordance to Equation (25) is less than tabulated value (from F-distribution table). The predicted or model values were obtained by substituting the pseudo components of the control mixes into the developed models.

2.3.3 Marshal Test Procedure

The marshall stability was determined according to [12].The Marshall stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain (50.8mm per minute). While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25 mm is called the Marshall flow value of the specimen.

III. Results and Discussion

3.1 HMA Stability Model

The results of the Stability values of trial points shown in Table 3, were used in the formulation of the HMA Stability model. With the help of Table 3 and Equation (24), the stability model coefficients for HMA using cement as filler for 4-2 polynomial was derived thus;

$B_1 = Y_1 = 10.459$ $B_{12} = 4Y_{12}- 2Y_1-2Y_2= 1.09$ $B_{24} = 4Y_{24}- 2Y_2-2Y_4= 18.326$
$B_2 = Y_2 = 8.224$ $B_{13} = 4Y_{13}- 2Y_1-2Y_3= 6.772$ $B_{34} = 4Y_{34}- 2Y_3-2Y_4= 10.092$
$B_3 = Y_3 = 8.059$ $B_{14} = 4Y_{14}- 2Y_1-2Y_4= 2.772$
$B_4 = Y_4 = 5.919$ $B_{23} = 4Y_{23}- 2Y_2-2Y_3= -0.681$

Substituting the above values into Equation (15), the optimization model for HMA using cement as filler becomes;

$$\tilde{Y} = 10.459X_1 + 8.224X_2 + 8.059X_3 + 5.919X_4 + 1.09X_1X_2 + 6.772X_1X_3 + 2.772X_1X_4 - 0.681X_2X_3 + 18.326X_2X_4 + 10.092X_3X_4 \quad (27)$$

Equation (27) represents the optimization model for predicting the stability of HMA using cement as a filler material. This model can be used to predict the stability of HMA using cement as a filler material of any arbitrarily given cement HMA constituents ratio and vice versa.

3.2 HMA Flow Model

The Marshall Flow test results obtained from the mix design of the trial points are as shown in Table 4. These flow values were used in this study for the development of flow model. With the help of Table 4 and Equation (24), the flow model coefficients for HMA using cement as filler for 4-2 polynomial was derived thus;

$B_1 = Y_1 = 4.27$ $B_{12} = 4Y_{12}- 2Y_1-2Y_2= -3.82$ $B_{24} = 4Y_{24}- 2Y_2-2Y_4= -14.70$
$B_2 = Y_2 = 6.54$ $B_{13} = 4Y_{13}- 2Y_1-2Y_3= -8.32$ $B_{34} = 4Y_{34}- 2Y_3-2Y_4= -12.04$
$B_3 = Y_3 = 7.13$ $B_{14} = 4Y_{14}- 2Y_1-2Y_4= -6.96$
$B_4 = Y_4 = 7.23$ $B_{23} = 4Y_{23}- 2Y_2-2Y_3= 2.58$

Substituting the above values into Equation (15), the flow optimization model for HMA using cement as filler becomes;

$$\tilde{Y} = 4.27X_1 + 6.54X_2 + 7.13X_3 + 7.23X_4 -3.82X_1X_2 - 8.32X_1X_3 - 6.96X_1X_4 + 2.58X_2X_3 - 14.70X_2X_4 - 12.04X_3X_4 \quad (28)$$

Equation (28) represents the optimization model for predicting the flow of HMA using cement as a filler material. This model can be used to determine the flow of HMA using cement as a filler material of any arbitrarily given cement HMA constituents ratio and vice versa.

3.3 Models Validation

Table 5 and Table 6 present the F-statistics used for the validation of the stability and flow models developed respectively. For the validation of the stability model, with the aid of Table 5 and Equation (26) the following was deduced;

$S_e^2= 0.01022/4=0.002555$; $S_m^2= 0.00240/4=0.001115$

The F-value which is the ratio of the two squared variances was computed using Equation (25) as;

F= 0.002555/0.001115=2.291

Because F-cal (2.291) is less than F-tab (6.388), the null hypothesis is accepted and the model was considered adequate.

For the flow model validation, with the aid of Table 6 and Equation (26), the following was deduced;

$S_e^2= 0.23312/4=0.05828$; $S_m^2= 0.15778/4=0.05173$

The F-value which is the ratio of the two squared variances was computed using Equation (25) as;

F= 0.05828/0.05173=1.127

Because F-cal (1.127) is less than F-tab (6.388), the null hypothesis is accepted and the model was considered adequate.

The stability and flow models proved adequate from the F-statistics analysis as the F- calculated were far lower than the tabulated F-value for both developed models. This signifies that these models can be used satisfactorily in the prediction of stability and flow values given any arbitrary mix design and vice versa.

Table 3. Stability Test Result for Trial Points

N	STABILITY TEST RESULTS					
	Z_1(Bitumen)	Z_2(C.A)	Z_3(F.A)	Z_4(Cement)	Response Symbol	Response (KN)
1	1	13.2	10.37	0.43	Y_1	10.459
2	1	11.40	7.22	0.38	Y_2	8.224
3	1	11.17	5.65	0.36	Y_3	8.059
4	1	7.83	7.29	0.55	Y_4	5.919
5	1	12.30	8.795	0.405	Y_{12}	9.614
6	1	12.19	8.01	0.395	Y_{13}	10.952
7	1	10.50	8.83	0.49	Y_{14}	8.882
8	1	11.285	6.435	0.37	Y_{23}	7.987
9	1	9.615	7.255	0.465	Y_{24}	11.653
10	1	9.50	6.47	0.455	Y_{34}	9.512

Table 4. Flow Test Result for Trial Points

S/N	FLOW TEST RESULTS					
	Z_1(Bitumen)	Z_2(C.A)	Z_3(F.A)	Z_4(Cement)	Response Symbol	Response (mm)
TP1	1	13.2	10.37	0.43	Y_1	4.27
TP2	1	11.40	7.22	0.38	Y_2	6.54
TP3	1	11.17	5.65	0.36	Y_3	7.13
TP4	1	7.83	7.29	0.55	Y_4	7.23
TP5	1	12.30	8.795	0.405	Y_{12}	4.45
TP6	1	12.19	8.01	0.395	Y_{13}	3.62
TP7	1	10.50	8.83	0.49	Y_{14}	4.01
TP8	1	11.285	6.435	0.37	Y_{23}	7.48
TP9	1	9.615	7.255	0.465	Y_{24}	3.21
TP10	1	9.50	6.47	0.455	Y_{34}	4.17

Table 5. F-Statistics for validation of Stability Optimization model

S/N	Exp.Value=Y_e	Mod. Value=Y^m	Y_e-$\hat{Y}_e$	Y^m-$\hat{Y}^m$	$(Y_e-\hat{Y}_e)^2$	$(Y^m-\hat{Y}^m)^2$
1	10.592	10.563	0.06820	0.03700	0.00465	0.00137
2	10.545	10.513	0.02120	-0.01300	0.00045	0.00017
3	10.487	10.534	-0.03680	0.00800	0.00135	0.00006
4	10.463	10.498	-0.06080	-0.02800	0.00370	0.00078
5	10.532	10.522	0.00820	-0.00400	0.00007	0.00002
	$\hat{Y}_e$=10.524	$\hat{Y}^m$ =10.526			∑=0.01022	∑=0.00240

Table 6. F-Statistics for validation of flow Optimization model

S/N	Exp.Value=Y_e	Mod. Value=Y^m	Y_e-$\hat{Y}_e$	Y^m-$\hat{Y}^m$	$(Y_e-\hat{Y}_e)^2$	$(Y^m-\hat{Y}^m)^2$
1	3.62	3.589	-0.08600	-0.04640	0.00740	0.00215
2	3.7	3.59	-0.00600	-0.04540	0.00004	0.00206
3	3.58	3.646	-0.12600	0.01060	0.01588	0.00011
4	3.51	3.402	-0.19600	-0.23340	0.03842	0.05448
5	4.12	3.95	0.41400	0.31460	0.17140	0.09897
	$\hat{Y}_e$=3.706	$\hat{Y}^m$ =3.635			∑=0.23312	∑=0.15778

IV. Conclusion and Recommendation

4.1 Conclusion

The mathematical models developed in this study for both stability and flow of bituminous concrete using cement as filler material can be relied upon in the prediction of these responses given any arbitrary mix ratio and vice versa. This is evident from the fact that values from both models compared well with their experimental counterparts at 5% level of significance through the F-statistics conducted.

4.2 Recommendations

The following points are hereby recommended from the outcome of this study;

- This model procedure be extended to other properties of HMA.

- Computer Programmes be written based on the models developed to hasten the optimization process for stability and flow values of HMA with cement as filler.

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