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MODELLING AND OPTIMIZATION OF LOCUST BEAN POD ASH CONTENT IN ASPHALT MIXTURE USING SURFACE RESPONSE METHODOLOGY

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ABSTRACT

Consumption of agricultural products generates large quantities of waste daily, and proper disposal mechanism is of great need. Introduction of waste pozzolanic material in asphaltic mixture creates a chemical reaction between bitumen and mineral filler as a result of its texture, geometry, chemical and mineralogical compositions. Mineral fillers play a significant role in the engineering properties of hot mix asphalt. The aim of the present study is to assess the effect of locust bean pod ash (LBPA) as mineral filler on the Marshall properties of hot mix asphalt. X-Ray fluorescence was used for characterization of LBPA, the results showed that LBPA oxide composition are comparable to that of granite dust which has been used as a conventional filler material. To accomplish this objective response surface methodology (RSM) was employed to examine the impact of LBPA on the conventional Marshall properties (Stability, Flow, VMA, Pa, VFB) of LBPA-modified asphalt mixture. By using Multi-objective process, a fifth regression model was considered with a p-value < 5% for all responses. ANOVA revealed that the LBPA had a significant effect on the Marshal properties investigated. After optimization the optimum values of LBPA and bitumen content are 40% and 50% and respectively. The predicated Marshall properties values for stability, flow, VMA, Pa and VFB are 7.639kN, 3.892mm, 18.311%, 3.63%, 78.549% respectively. The findings of this study showed that LBPA is suitable as a mineral filler in asphaltic mixture.

Keywords: Asphalt, Locust Bean Pod Ah, Marshall Properties. Optimization, Response Surface Methodology

INTRODUCTION

Hot mix asphalt is a composite mixture comprising of bitumen as a binder and is approximately 4-8% of the asphaltic mix by weight, other constituent material is fine and coarse aggregate usually 78-87% of the mix this includes mineral filler (Little et al., 2016; Nwaobakata & Eme, 2018). A filler material are materials finer than 0.075μm this can be crushed rock fines, Portland cement or hydrated lime. Recent researches have showed that waste materials having pozzolanic properties can serve as a mineral filler. Portland cement, saturated lime and other waste materials (additive) are often added to natural filler 4 or 7% by mass of total mix to improve the adhesion of the bitumen to the aggregate. Filler plays a pivotal role in asphaltic mixture on voids content and the stiffness of the bitumen matrix. It is now an accepted practice in engineering to convert agricultural waste into useful material to improve the properties of concrete, soil and hot mix asphalt, these locally available waste materials are considered to be economically viable. One of the local materials been considered is the ash obtained from the combustion of the waste from the locust bean fruit, it has three components namely: the seeds are predominantly used to for local seasoning of food; the powder and the husk. The husk is the waste product and when burnt in open air will eventually result into locust bean waste ash (LBWA) The locust bean tree is common in our environment and it grows to about 15 m in height and has dark evergreen pinnate leaves. The fruit is brown, leathering pod about 10 to 30 cm long. The seed are edible but the waste product litter our environment with corresponding negative environmental impact. The treatment of soil with locust been waste ash could be a viable way to ameliorating this social menace (Salawu, 2011). Response Surface Methodology (RSM) was developed by Box and Wilson (1951) for experimental data analysis, development of models and optimal response. RSM is a collection of mathematical-statistical tools applied to the creation of data adaptation. Models by means which a series of parameters can be optimized and interactions that are produced between them. RSM accesses the best model that can predict the responses as a fitted surface and gives the best point of the surface based on the goal of the objective of the designer. The main purpose of adopting RSM is to obtain the best conditions of a process that satisfies the operating specifications. RSM optimization is basically a 3-step process which include first design of experiments, second calculation of coefficients in a mathematical model, third response prediction and examining the acceptability of the model within the framework of the model (Behera et al., 2018).

Ibedu et al., (2023) experimented on the compressive strength and water absorption of cement locust bean waste ash blended for latcrete blocks production. Their study involved the production 9th hollow latcrete block of a 225 x 225 x 450mm dimension. The chemical test conducted on the locust bean waste ash detected silicon oxide (SiO_2) at 51.4%, aluminium oxide (Al_2O_3) at 18.18%, ferric oxide (Fe_2O_3) at 15.6%, titanium oxide (TiO_2) at 0.55%, calcium oxide (CaO) at 5.31%, sulfur trioxide (SO_3) at 1.48%, potassium oxide (K_2O) at 0.88%, Manganese (II) oxide (MnO) at 0.15% and LOI at 3.33%. The blocks was tested for strength and water absorption, mix ratio used was 1:6 and locust bean was used to replace cement from 5 – 10% (at interval of 5%) by weight of the cement. Their study conclude that locust bean pod ash is a class F pozzolan and that 20% locust bean pod ash displayed an adequate strength conformity for dry strength and water absorption as specified by Nigerian industrial standard. The authors in their research did not consider the effect locust bean pod ash in an asphaltic mixture neither did they use RSM technique in the study.

Olubajo et al., (2020) experimented the effect of locust bean pod ash and eggshell ash on the mortar compressive and flexural strengths of cement blends. In the research the oxide composition of locust bean pod ash was conducted via X-Ray fluorescence. The oxide composition of locust bean pod ash contained S_iO_3+Al_2O_3+Fe_2O_3 met the requirement of ASTM

C168-01 for a material to be used as a pozzolan. The material was classified as Class C pozzolan. The peak strength of the mortar 6.5N/mm^2 was obtained at 28 days curing with 2.5% and 10% replacement of cement with locust bean pod ash respectively. The study concluded that a blend of egg shell and locust bean pod ash has the potential to enhance the flexural strengths of mortar. The authors did not use Response Surface Methodology technique in analyzing the effect of locust bean pod ash on compressive strength of concrete,

It is important to investigate the use of locust bean pod ash as a filler material in hot mix asphalt as it has become an attractive prospect to source mineral fillers from waste generated from agricultural product. Therefore the main objective of this study is to partially replace granite dust with locust bean pod ash (LBPA). RSM was used to design, model and optimize and establish optimum LBPA content. The effect of LBPA on stability, flow, voids in mineral aggregates (VMA), total voids in mixture (Pa) and voids filled with bitumen (VFB) was demonstrated using 3D surface plots and ANOVA was used to formulate a statistical model for each independent variable

MATERIALS AND METHODS

Materials

i. The materials to be used for this research include the following;
ii. Locust bean pod ash
iii. Bitumen,
iv. Coarse and fine aggregate.
v. Design Expert version 13

Methods

The test on locust bean pod;

X-Ray fluorescence (XRF) in accordance with ASTM E1621-13 (2013)

Analysis and Design of Response Surface Methodology Based Experiment

Table 1 shows the levels of the experimental data, ranges and the independent variables being considered. Response Surface Methodology (RSM) processed a total analysis of 84 runs carried out in erratic order for each response analyzed. The dependent variables been considered for evaluation are Marshall stability and flow, Voids in Mineral Aggregates (VMA), Percent air voids (Pa) and Voids Filled with Bitumen (VFB), the experimental runs was randomized which helps to reduce the effect of error and uncontrolled factors. The accurate regression used for estimating the two factors (independent variables) and the establishing the responses (dependent variables) in the analysis is given in equation 1

$$Y = b_o + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij} x_i x_j + \varepsilon \quad (1)$$

Where Y = the responses (stability, flow, VMA, Pa and VFB)
x_i and x_j = factors (percentages of LBPA and bitumen)
b_i and b_{ii} = linear and fifth terms
b_{ij} = interaction term coefficient
ε = random error of the model and the studied numbers of the factors

Analysis of variance (ANOVA) was carried out to assess the validity of the model and the correlations among the independent parameters. The analysis of variance tests and assesses the validity of the given models and the importance of individual factor. The R^2 and adjusted R^2 (that is, coefficient of determination) represents the accuracy of the suggested model. Equations 2 and 3 can be applied to get the respective values.

$$R^2 = 1 - \frac{SS_{res}}{SS_{res} + SS_{mod}} \quad (2)$$

$$R_{adj}^2 = 1 - \frac{SS_{res}/DF_{res}}{(SS_{mod} + SS_{res})/(DF_{mod} + DF_{res})} \quad (3)$$

Where R^2 and R_{adj}^2 = coefficients of determination
$SS_{res,} SS_{mod} DF_{res} DF_{mod}$ = Models sum of squares and degree of freedom respectively.

Table 1: Design Experiment Data

Run	Factor 1	Factor 2	Response 1	Response 2	Response 3	Response 4	Response 5
	Bitumen (%)	LBPA (%)	Stability (kN)	Flow (mm)	VMA (%)	Pa (%)	VFB (%)
1	5	50	9.5	3.5	17.18	6.1	66.11
2	5	50	9.3	3.63	17	6	60.81
3	6	20	8	3.55	17.02	4.01	78.92
4	6.5	20	7.2	4.2	17.47	3.58	82.72
5	6.5	30	7.49	3.69	18.16	3.77	81.73
6	6.5	30	7.7	3.88	18	3.59	77.5
7	6.5	40	8.1	3.8	18	3.61	83.44
8	4	10	8.25	2.9	16.76	8.56	56.61
9	4.5	30	8.1	3	16.99	6.55	60.55
10	6	30	8.9	3.1	17.66	4	70.69
11	4	10	8.55	2.5	16.59	7.23	50.69
12	4	20	4.9	2.9	16.69	8.04	50.22
13	4	20	4.45	2.35	16.88	8	54.17
14	5.5	10	8.4	3.4	17.53	5.81	70.03
15	6.5	40	7.6	3.4	18.22	3.81	75.99
16	4	30	7.5	2.8	17.36	8.9	51.53

17	6	30	7.7	3.65	17	3.89	76.22
18	6	40	8	3.85	17.07	4.97	70.69
19	5.5	10	8.99	3.99	17.62	5	68.14
20	4.5	30	8.6	3	16.67	7.29	56.67
21	5.5	20	8.6	3	16.63	5	72.49
22	5.5	20	7.8	3.8	16.11	5.18	78.5
23	4.5	40	8	2.69	16.84	6.35	63.33
24	6.5	50	7.95	5.5	18.5	4.06	79.39
25	4.5	40	9.6	2.89	16.4	6.99	56.4
26	4.5	50	8.81	3.21	16.99	6	53.15
27	6.5	50	8.33	4.9	18.26	4	77.17
28	6	40	8.4	3.84	18.88	4.51	76.22
29	4.5	50	8.45	3.45	16.77	7.93	63.75
30	7	10	6.3	5.3	20	4.99	81.88
31	4	30	7.9	2.9	16.89	7.9	50.29
32	4	40	8.4	2.27	17.04	8.65	53.14
33	5.5	30	9.15	3.15	16.32	5.58	78.81
34	5	10	8.5	2.9	17.29	5.65	68.89
35	7	10	6.2	5.89	20	4.51	70.49
36	5	10	8.69	2.89	16.58	6.1	61.55
37	5.5	30	7.88	3.28	16.57	6.8	70.43
38	7	20	6.8	5	18.82	3.79	80.65
39	5.5	40	8.91	2.91	17.01	5.35	73.29
40	6	50	8.1	4.6	17.46	3.8	79.55
41	5	20	8.2	3.2	16.5	5	70.18
42	5	20	7.3	3.3	16	5.18	67.31
43	5.5	40	8.78	2.98	18.88	5.99	70.31
44	5	30	8.6	3.3	17.11	5.58	63.22
45	6	50	9.4	4.4	17.01	3.96	74.61
46	5	30	8.6	3.35	17.24	6.8	65.22
47	7	20	6.3	5	19	3.16	82.72
48	5.5	50	8.1	3.9	17.5	6.1	74.61
49	5.5	50	9.4	3.8	17	6	65.97
50	4	40	7.9	2.33	17	7.89	49.16
51	6	10	7.5	4.5	18.55	5	71.98
52	6	10	7.9	3.9	18.11	5.3	70.82
53	4	50	7.55	2.45	16.5	8.11	50.98
54	6.5	10	7.9	4.5	19.71	5.52	70.19
55	4	50	7.98	2.28	16.9	7.73	53.82
56	7	30	6.77	3.95	18	4	75.18
57	6	20	8	3.65	17.53	3.81	75.24
58	6.5	10	7.2	5.5	19	4.81	76.35
59	5	40	9.55	2.55	16.85	5.35	69.11
60	5	40	9.8	2.8	16.65	5.99	63.27
61	7	30	6.99	5	18.8	4.1	83.17
62	6.5	20	7.6	4.6	18	3	80.65
63	4.5	10	8.91	2.85	16.76	6.5	60.11
64	7	40	6.5	4.5	19.23	3.11	84.05

65	7	40	7.1	4.1	18.52	3.76	79.43
66	4.5	10	8.1	2.75	16.59	7	59.05
67	4.5	20	8	3	16.08	6.11	60.99
68	4.5	20	8.2	3	16.88	6.97	59.11
69	7	50	6.63	4.9	19.18	4	82.18
70	7	50	7.1	5.1	19.58	4.04	76.07
71	4	0	8.01	3.1	17.64	8.46	45.99
72	4	0	8	3.2	16.6	8.33	55.95
73	4.5	0	8.2	3.4	17	7.27	55.47
74	4.5	0	8.16	3.3	17.1	7.1	60.33
75	5	0	8.22	3.4	17.66	6.33	60.39
76	5	0	8.1	3.39	17	6.21	66.47
77	5.5	0	8.3	3.94	16.72	4.5	76.37
78	5.5	0	8.26	3.26	16.95	4.44	70.21
79	6	0	8.32	4	17.6	4	70.05
80	6	0	8.3	4	17.73	4.8	80.27
81	6.5	0	8	4.3	17.34	3.46	80.35
82	6.5	0	7.2	4.1	17	3.1	82.95
83	7	0	7.24	4.61	18.32	3.12	83.09
84	7	0	7.1	4.79	18.37	3.23	83.07

RESULTS AND DISCUSSIONS

Chemical Composition of Locust Bean Pod Ash

The result of chemical composition test is shown in Table 2. Based on ASTM C168-19 (2019) classification, the locust been pod ash can be group as class C pozzolan. This grouping is upon the summation of Silica (SiO_2) + Alumina (Al_2O_3) + Iron (Fe_2O_3). The summation of this oxides for locust bean pod ash was 71.53% and also based on the value of loss on ignition (6.21%). Although pozzolanic reaction does not occur in hot mix asphalt, the chemical composition test is necessary for characterization of the filler material Chemical composition of mineral filler plays a major role in the adhesion among filler, aggregates and bitumen. As stated by Chen et al., (2020) the activity of filler material can be divided into two namely physical hardening and chemical adhesion; the chemical activity is the chemical reaction between alkaline components of filler and bitumen. This is necessary to explain the effect of locust bean pod ash in hot mx asphalt. These results are similar to the values obtained by Olubajo et al., (2020) and Ibedu et al., (2023).

Table 2: Chemical Composition of Locust Bean Pod Ash

Oxide	AlO_3	Fe_2O_3	MgO	Na_2O	CaO	P_20_5	K_2O	LOI
%Composition	15.13	9.27	3.2	0.6	10.79	2.98	3.54	6.21

Analysis of Variance and Model Development

The analysis of variance results for the suggested models are shown in Table 3. For the two dependent variables, fifth was the suggested regression model and it reveals that all built models fit correctly with the learned constant. The criteria for choosing the fifth models was based on the highest order of polynomials, where all supplementary terms are significant and not indicated as aliased by the design expert software. The independent variables (Bitumen and LBPA) are denoted as A and B in the predicted models as shown in equation 4 – 8. Only essential variables of impact are revealed in the equations

$$\text{Stability} = +8.24 - 0.5455A_1 + 189B - 0.5019AB - 0.13A^2 + 2.06B + 0.8027A^2B - 3.54AB^2 + 1.09A^2 - 6.38B^2 + 1.09A^3 - 6.38B^3 + 0.2818A^3B + 0.2805AB^3 - 0.1698A^4 - 1.72B^4 - 0.99A^3B^2 - 1.08A^2B^3 - 0.2781A^4B + 3.71AB^4 - 0.1789A^4 + 4.90B^5 \quad (4)$$

$$\text{Flow} = +3.26 + 0.7781A - 0.3662B - 1.01AB + 0.9713A^2 - 0.0108B^2 + 0.3860A^2B + 2.00AB^2 - 0.4581A^3 - 0.7697B^3 - 0.4563A^2B^2 + 0.0391A^3B + 1.28AB^2 - 0.4679A^4 + 0.5563B^4 - 0.4558A^3B^2 + 0.0049A^2B^2 - 0.6454A^4B - 1.44AB^4 + 0.5898A^5 + 1.29B^5 \quad (5)$$

$$\text{VMA} = +16.72 + 1.17A + 1.05B - 1.18AB + 0.826A^2 + 2.77B^2 - 0.8125A^2B + 2.02AB^2 - 0.625A^3 - 4.34B^3 - 0.3190A^2B^2 + 0.0546A^3B + 1.51AB^3 + 0.1181A^4 - 2.29B^4 + 0.9856A^2B^3 + 0.0723A^4B - 2.73AB^4 + 0.11A^5 + 3.31B^5 \quad (6)$$

$$\text{Pa} = +5.06 - 2.30A + 2.15B - 1.22AB - 0.4727A^2 + 1.60B^2 - 2.01A^2B + 1.93AB^2 - 0.1081A^3 - 0.16B^2 - 2.01A^2B + 1.93AB^2 - 0.1081A^3 - 8.24B^2 - 0.1626A^2B^2 + 0.2234A^3B + 1.25A^4 - 1.37B^4 + 0.5441A^3B^2 + 0.4383A^2B^3 + 1.37A^4B - 2..37AB^4 - 0.0160A^5 + 6.45B^5 \quad (7)$$

$$\text{VFB} = +71.54 + 14.38A - 0.0177B - 0.00142AB - 5.24A^2 - 0.6320B^2 \quad (8)$$

Analysis of Variance was carried out to appraise the acceptability and significance of the models suggested and the results are shown in Table 3. The degree of fitness of the models generated was appraised based on the coefficient of determination (R^2). The R^2 values for the dependent variables, Stability, flow, VMA, Pa and VFB are 0.7593, 0.9307, 0.8416, 0.9269, and 0.8851 respectively. A greater R^2 value implies an improved agreement between the predicted values and experimental values. The predicted R^2 for Stability, flow, VMA, Pa and VFB are 0.5772, 0.8625, 0.7312, 0.8725 and 0.8655 are in reasonable agreement with the adjusted R^2 which are 0.6829, 0.8956, 0.7913, 0.9037 and 0.8778 respectively since the difference is less than 0.2. Adequate precision estimates the signal-to-noise ratio, an adequate precision greater than 4 is considered desirable. The adequate precision obtained for all five dependent variables are 12.8001, 25.4570, 18.6311, 22.1929 and 30.0040, since all the adequate precision for all variables are greater than 4 hence the models can be used to navigate the design space.

Analysis of variance presented in Table 3 shows the dependent variable model. All dependent variable are estimated in the 95% confidence level where p-value is < 0.05. Models with greater F-values like 9.94, 36.6, 16.73, 39.94 and 120.23 shows the importance of models with lower p-values of 0.0001 which is less than 0.05. The lack of fit t-test was used to gauge the suitability of the model. Lack of fit shows the variation fluctuation of the data in the model, expect for stability, all lack of fit calculated are not significant, this implies that the models chosen can be used to explain the relationship among the dependent and independent variables. However the significant lack of fit observed at stability does not mean that the model should be discarded since adequate precision was recorded among the predicted R^2 and adjusted R^2 therefore the model can be used to navigate the design space to find the best condition.

Table 3: Analysis of Variance results for the response

Source	SS	DF	MS	F-Value	P-Value	Remark	Model
Stability							**Fifth**
Model	54.85	20	2.74	9.94	< 0.0001	significant	
Residual	17.39	63	0.276				
Lack of Fit	9.45	21	0.4499	2.38	0.0083	significant	
Pure Error	7.94	42	0.1891				
Cor Total	72.24	83					
R^2	0.7593						
Adjusted R^2	0.6829						
Predicted R^2	0.5772						
Adequate Pre.	12.8001						
Flow							**Fifth**
Model	53.22	20	2.68	36.6	< 0.0001	significant	
Residual	4.61	63	0.0731				
Lack of Fit	1.43	21	0.068	0.8977	0.5945	Not significant	
Pure Error	3.18	42	0.757				
Cor Total	58.12	83					
R^2	0.9307						
Adjusted R^2	0.8956						
Predicted R^2	0.8625						
Adequate Pre.	25.4570						
VMA							**Fifth**
Model	61.88	20	3.09	16.73	< 0.0001	significant	
Residual	11.65	63	0.9177				
Lack of Fit	4.29	0.204	1.16	0.3287	0.3287	Not significant	
Pure Error	7.36	42	0.1753				
Cor Total	73.53	83					
R^2	0.8416						
Adjusted R^2	0.7913						
Predicted R^2	0.7312						
Adequate Pre.	18.6311						
Pa							**Fifth**
Model	200.47	20	10.02	39.94	< 0.0001	significant	
Residual	15.81	63	0.2510				
Lack of Fit	7.26	21	0.3457	1.70	0.0715	Not significant	
Pure Error	8.55	42	0.2036				
Cor Total	216.28	83					
R^2	0.9269						
Adjusted R^2	0.9037						
Predicted R^2	0.8725						
Adequate Pre.	22.1929						
VFB							**Fifth**
Model	8062.77	5	1612.55	120.23	< 0.0001	significant	
Residual	1046.17	78	13.41				

Lack of Fit	363.96	36	10.11	0.6224	0.09255	Not significant
Pure Error	682.21	42	16.24			
Cor Total	9108.84	83				
R^2	0.8851					
Adjusted R^2	0.8778					
Predicted R^2	0.8655					
Adequate Pre.	30.0040					

Plots of Predicted Values and Actual Values

The plots of predicted values and actual values are assessed to gain a vivid explanation of the sufficiency of the models developed. The plots of predicted values and actual values are revealed in Figure 1 (a - e). It was observed from the figures that all the point were moderately distributed close to the line of equality, this implies that the models developed have an acceptable level of precision. Moreover the distributions of all points from enclosed line in the plots revealed an impressive correlation between the predicted values and experimental values.

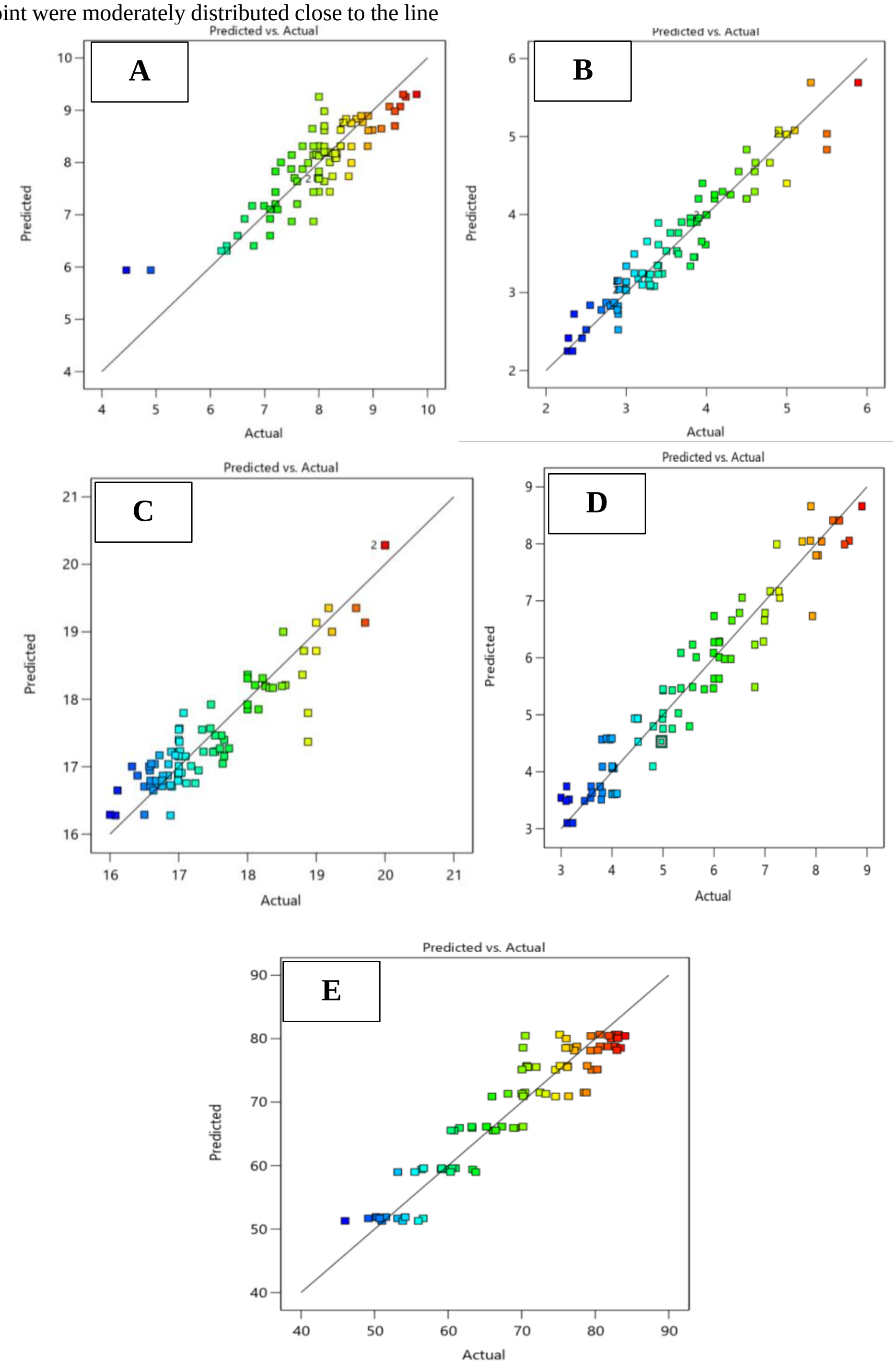

Figure 1: RSM plots for the predicted versus actual (a) Stability (b) Flow (c) VMA (d) Pa (e) VFB

2D and 3D Contour Plots of Marshall Properties

Marshall Stability

The interrelationship between the dependent variable Marshall stability and independent variable bitumen content and LBPA Content is presented in Figure 2(a and b). The egg-shaped yellow and green colour of the 2Dplots of Figure 2b shows signifies the excellent interrelationship between the dependent and independent variables. Figure 2b also shows that both the dependent and independent variables have a major effect on the Marshall Stability. The Marshall stability recorded an increase with increase in LBPA content from 0% to 40% (interval of 10%) with bitumen content from 4% to 7% (interval of 0.5%). However there was a decreases observed at 50% LBPA content across all bitumen content variations. This increase could be attributed to the uniform dispersing of locust bean pod ash in the mixture which created an active adhesion reaction between the bitumen and aggregate. Mehari (2007) also stated that the addition of fillers will increase the binder viscosity and thus increasing the stability values. Moreover, both the dependent and independent variable displayed a major interrelationship effect on the Marshall stability.

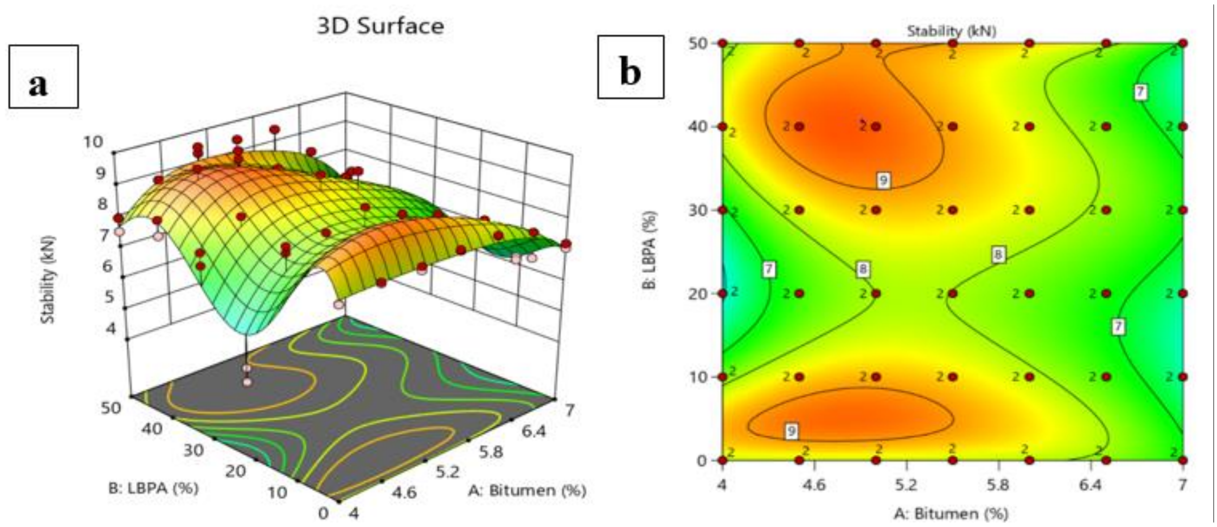

Figure 2: Effect of bitumen content and LBPA on Marshall Stability (a) 3D (b) 2D

Marshall Flow

The interrelationship between the dependent variable Marshall flow and independent variable bitumen content and LBPA Content is presented in Figure 3(a and b). The interrelationship between the dependent and independent variables shown in Figure 3 suggests that a linear relationship exist the dependent variables and independent variables, that is, as LBPA content and bitumen content increases there is a corresponding increase in the Marshall flow values. Marshall flow measures the rate of deformation of asphalt with increase the force applied

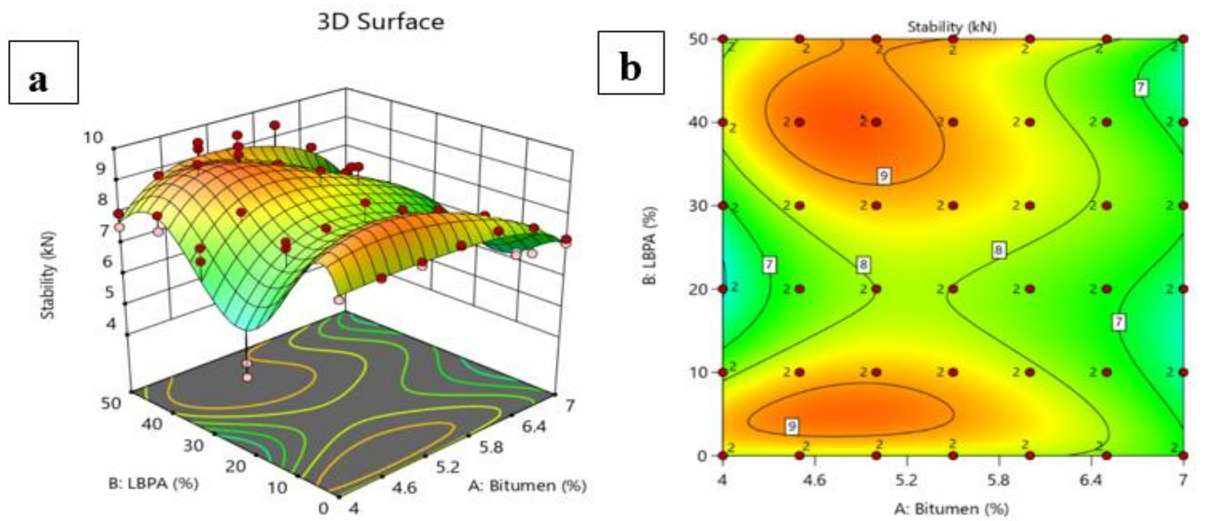

Figure 3: Effect of bitumen content and LBPA on Marshall Flow (a) 3D (b) 2D

Voids in Mineral Aggregate (VMA)

The interrelationship between the dependent variable voids in mineral aggregate (VMA) and independent variable bitumen content and LBPA Content is presented in Figure 4(a and b). It was noted that the VMA decreases with increase in bitumen content. The VMA indicates existing voids between aggregates particles which did not get absorbed by bitumen as in the percent air voids (Pa), VMA also impacts on the mechanical strength, durability and impermeability of the sample

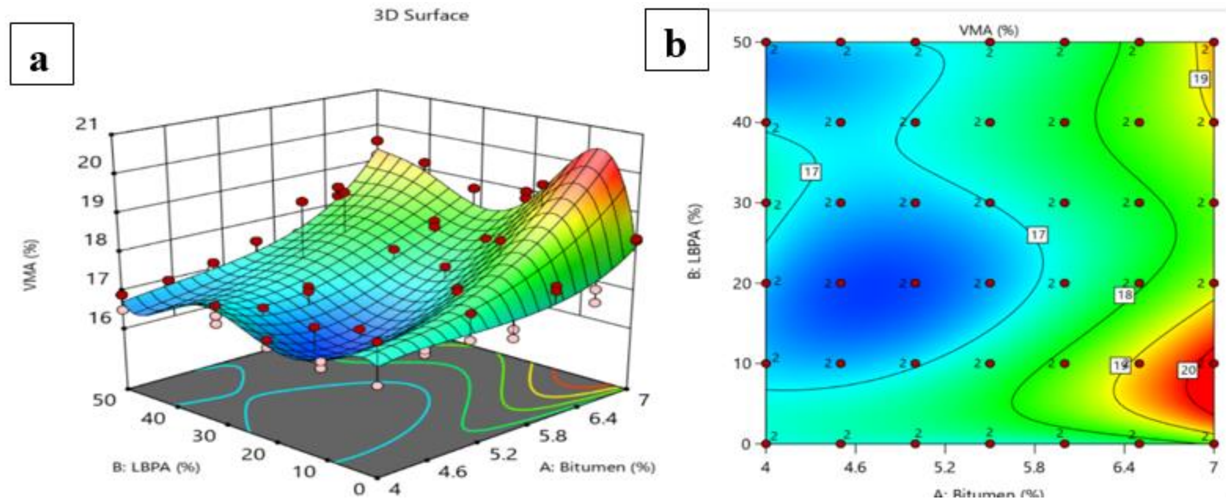

Figure 4: Effect of bitumen content and LBPA on VMA (a) 3D (b) 2D

Percent Air Voids (Pa)

The interrelationship between the dependent variable percent air voids (Pa) and independent variable bitumen content and LBPA Content is presented in Figure 5 (a and b). The relationship between bitumen content and LBPA content is obviously shown in Figure 5a. The percent air void in the total mixture is very significant in the sense that the percent air void in the total mixture the mechanical strength, durability and impermeability of the sample. It can be noted that as the bitumen content increased from 4% to 7% and LBPA increases from 0% to 50% the observed voids in the mixture decreases.

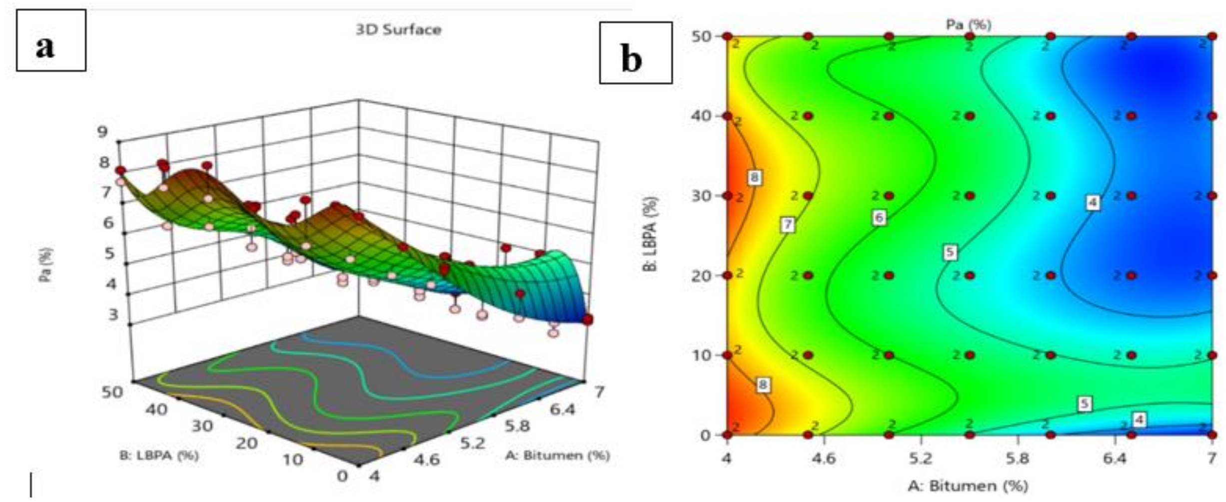

Figure 5: Effect of bitumen content and LBPA on Pa (a) 3D (b) 2D

Voids Filled Bitumen (VFB)

The interrelationship between the dependent variable voids filled with bitumen (VFB) and independent variable bitumen content and LBPA Content is presented in Figure 6(a and b). It can be noted from Figure 6(a and b) that an excellent interrelationship exist between the independent and dependent variables. The VFB values increase with increase in LBPA content. This behavior can be attributed to the adhesive chemical reaction between the LBPA and bitumen which caused the LBPA to fill the surplus voids between the aggregates with increase in bitumen content

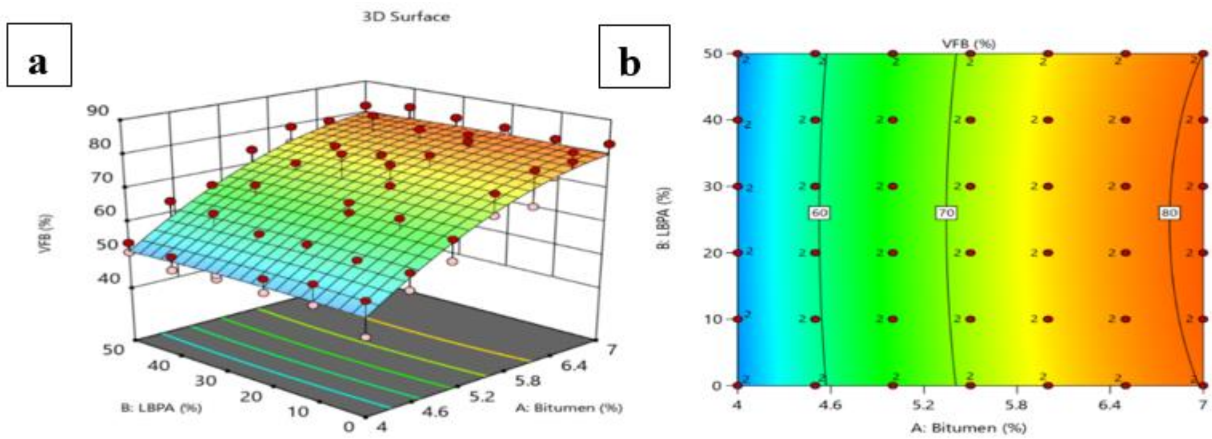

Figure 6: Effect of bitumen content and LBPA on VFB (a) 3D (b) 2D

Optimization

Table 4 shows the criteria used in selecting the parameters for the numerical optimization, that is, the desired goals, responses optimized and the respective limits. The maximum predicted values for LBPA, bitumen, stability, and VMA are 40%, 5%, 7.639kN, 18.311% respectively. For flow, Pa and VFB the in range prediction values are 3.892mm and 3.63% and 78.549% respectively. The optimized ramps for the LBPA-Bitumen content and desirability result is presented in Figure 6. The optimized ramps for LBPA-Bitumen indicates the desirability of the responses ranging from 0 (worse case) to 1 (optimal case). The Dots on the ramps indicates the optimal value for the independent variable behavior

Table 4: Criteria for selecting Marshall Mix Design Numerical Optimization

Response	Unit	Lower Limit	Upper Limit	Desired Goal
Bitumen	%	4	7	Maximize
LBPA	%	0	50	Maximize
Stability	kN	4.45	9.8	Maximize
Flow	mm	2	4	In range
VMA	%	16	20	Maximize
Pa	%	3	8.9	In range
VFB	%	45.99	84.05	Target

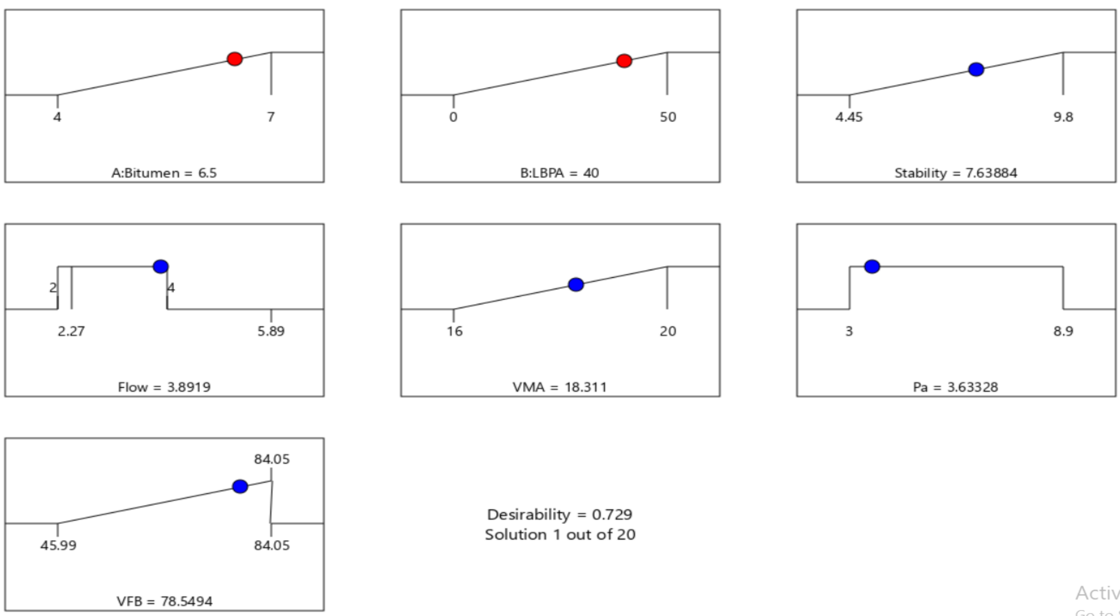

Figure 7: Optimized Numerical ramps for LBPA-Bitumen

CONCLUSION

The chemical composition of the locust bean pod ash satisfies the requirement of ASTM C168-19 and can be group as class C pozzolan as it contains (SiO_2) + (Al_2O_3) + (Fe_2O_3) ≥ 70% making a good mineral filler for hot mix asphalt. The physical properties of the locust bean pod ash met he requirement of ASTM D546-17 and as such is suitable for use a mineral filler in hot mix asphalt. The fifth model developed for the purpose of mathematical experimental design and optimization was found to be suitable for predicating and understanding the interrelationship effect that exist between the factors and responses. Considering that all responses showed a high R^2

and adequate precision greater than 4 is considered desirable and efficient for optimizing experimental conditions.

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