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Evaluation of Volumetric Properties of Cassava Peel Ash Modified Asphalt Mixtures

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Abstract

In continuance to providing a reliable and cost-efficient road construction material that would aid the development of sustainable pavements while also eradicating agricultural wastes to protect the environment, Cassava Peel Ash (CPA) modified asphalt mixture is seen to be one of the most viable options. This study aimed to determine the suitability of Cassava Peel Ash (CPA) in hot mix asphalt for improved pavement performance. Using response surface methodology, a central composite design was employed for the mix design parameters, namely coarse aggregate (CA), fine aggregate (FA), mineral filler (MF), bitumen content (BC), and cassava peel ash (CPA). CPA was used as a partial replacement for filler and varied between 0% and 20%. The BC varied between 4% and 8%, the MF varied between 15% and 20%, the FA varied between 10% and 14%, and the CA varied between 46% and 52%. The interactive effect between the mix design parameters on the volumetric properties of the asphalt mixtures was evaluated. The results obtained showed the Marshall stability, flow, density, volume of the void, and void in mineral aggregates of the asphalt mixtures at 1.8037–8.045 kN, 2.7-8.22 mm, 2.0426–2.3909%, 1.094–7.966% and 55.5105–93.1393% respectively. These results indicate that the interaction of CA, FA, MF, BC, and CPA influences the volumetric properties of asphalt mixtures. From the RSM analysis, a prediction model and an optimal condition of 4.018% asphalt content, 20% cassava peel ash, 46% coarse aggregate, 10% fine aggregate, and 15% mineral filler were achieved for the asphalt mixtures.

Keywords: Hot Mix Asphalt; Cassava Peel Ash; Marshall Stability; RSM; Pavement Engineering.

1. Introduction

In addition to focusing on sustainability, the asphalt pavement sector is dedicated to innovation in pavement construction [1, 2]. A well-known technique for producing durable pavements involves combining aggregates with asphalt binder and applying heat and pressure to the mixture [3, 4]. The mineral filler is one of the main components of these asphaltic mixtures. They are small, naturally occurring particles that typically pass US Standard Sieve No. 200 that make up the mineral filler used in pavement mixtures [5]. The filler interacts with itself and with other constituent aggregates to assist in stiffening the mix and resisting shearing pressures on the pavement [6]. It adds to the aggregate skeleton's strength by providing additional contact points and forms a high consistency matrix that serves as a cement coarse aggregate together at the mortar level after being combined with a binder [7].

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Engineers and specialists are working to improve the qualities of asphalt mixtures to extend the life of asphalt pavement. The use of additives such as fibers and polymers to improve the qualities of asphalt mixtures is standard practice [8, 9]. Similarly, the proliferation of various industries, combined with population growth, has resulted in a huge increase in the production of waste materials around the world. Waste resources offer the advantages of being both cost-effective and ecologically friendly when used as secondary materials [10, 11]. Recent research efforts focus on incorporating recycled materials to enhance the properties of the mix. The recycled materials come from a variety of sources, including building, agricultural, and industrial waste. These various types of waste include hospital waste, agricultural waste, plastic waste, and industrial waste. The majority of these waste materials are either non-degradable (waste plastics, synthetic polymers, scrap tires, tire tubes, etc.) or degradable (cassava peels from cassava processing waste, as used in this study). In traditional bituminous mixes, they are typically employed as partial or total substitutions for coarse, fine, and filler aggregates [2]. The viability of using several degradable materials as fillers in asphalt concrete is being explored. For example, materials like rice husk ash, date seed ash, periwinkle shells, cow-bone ash, and milled egg shells [12-16].

Cassava peel (CP), which is a by-product of cassava processing, accounts for 20–35 percent of the tuber's weight, especially when peeling by hand [17]. Cassava peels are discarded indiscriminately due to gross under-utilization and a lack of sufficient technologies to recycle them, posing a major challenge and resulting in an environmental problem. As a consequence, there is a need to look for new ways to recycle it. The utilization of waste materials in road construction is a sustainable practice that will encourage waste reduction, a cleaner environment, and cost savings in road construction works, as well as serving as an alternative material [18]. Recent research has explored use of cassava peel ash as stabilizing agents for lateritic soils for pavement foundations [19] and strength modifiers for concrete.

Raheem et al. [20] in their research study partially replaced cement in concrete with CPA at varying proportions (0% to 20% by cement weight at 5% interval) using a mixture ratio of 1:2:4 and cured for 7 to 28 days. The strength development and slump were observed and it was concluded that the concrete strength increases with the increased hydration period but decreases with the increased quantity of the CPA. Also, Ofuyatan et al. (2018) [21] investigated cassava peel ash, which is locally available and utilized as a supplementary cementation material, to partially replace conventional cement in concrete at a varying ratio from 5% to 25%. The strength properties of the CPA concrete cured for 7 days to 180 days are determined in terms of compressive strength, flexural strength, porosity, durability, slump, water absorption, and shrinkage. From their results summary, 10% to 15% produced the optimal results for the response parameters. Other research carried out on the use of Cassava peel ash in concrete is also outlined in [22-27]. Following these developments and the limited research in exploring cassava peel ash use in asphalt, this study aims to evaluate the effects of cassava peel ash as a mineral filler on the engineering characteristics of asphaltic concrete.

2. Materials and Method

This study is based on laboratory testing and analysis. All tests were conducted using the equipment and devices available in the Civil Engineering laboratories of Landmark University, *Omu-Aran*, Kwara State, Nigeria. The materials used for this study are the basic constituents of Hot asphalt mix namely: bitumen, coarse aggregate, fine aggregate, filler (stone dust), and cassava peel ash.

2.1. Materials

The coarse aggregate (granite), fine aggregates (river bed sand), as well as the conventional filler (stone dust) were obtained from Landmark University, *Omu-Aran*, Kwara State. The Bitumen used was sourced from the local market. The Cassava peel was sourced from Ondo state. The materials were subjected to various laboratory tests to determine their appropriateness according to standard specifications. The materials utilized are shown in Figure 1. Physical tests such as particle size distribution (ASTM D2487-17 [28]), Specific Gravity (ASTM C127-15 [29]), Aggregate Impact (ASTM D5874-16 [30]), Aggregate Crushing, LA Abrasion (ASTM C131-06 [31]), Bulk Density (ASTM C128-15 [32]), Flakiness Index & Elongation Index (ASTM D4791-19 [33]) and Density tests were carried out on the aggregates. Penetration (EN1426:2015, IS:1203, and AASTHO D-5 [34-36]), Ductility (IS:1208 and ASTM D-113) [37, 38], Fire Point (IS:1209 [39]), Viscocity (IS:1206 (PART II) and ASTM D-2171-07 [40, 41]), Specific Gravity (ASTM D70-18a [42]), Softening point (BS EN 1427:2015, IS:1205 and ASTM D36-06 [43-45]), Flash Point (ISO 2592:2017 and ASTM D92-18 [46, 47]), Loss on heating (IS:1212 [48]), and Moisture Content (IS:1211 [49]) were all carried out on the bitumen. The properties of these materials are shown in Tables 1 and 2.

(a) (b) (c) (d)

Figure 1. Materials (a) Stone dust (b) Granite (c) CPA (d) Bitumen

Table 1. Aggregate Properties

Parameters Tested	Fine Aggregate	Coarse Aggregate	Specification
Particle Size Distribution	Cu= 3.03, Cc= 1.00	Cu= 3.23, Cc= 1.13	ASTM D2487-11 [28], 1≤Cc≤3
Specific Gravity	2.7	3.2	3% Maximum
Aggregate Impact Test	-	15.9%	30% Maximum
Aggregate Crushing Test	-	44.93%	45% Maximum
Los Angeles Abrasion Test	-	47.45%	60% Maximum
Flakiness Index	-	28.62%	30% Maximum
Elongation Index	-	29.53%	30% Maximum
Density	-	1840.2 kg/m^3	

Table 2. Test on Bitumen

Parameters	Trail ID			Average	Specification	Test Method
	A	B	C	Results		
Penetration @25c	82	89	78	83	60-70	EN1426:015 [34], IS:1203 [35], and AASTHO D-5 [36]
Ductility @25c	91	86	90	89	100Min.	IS:1208 [37], and ASTM D-113 [38]
Fire point	298	305	308	303.7	≥ 250	IS:1209 [39]
Viscosity	2740	2820	2700	2753	2400Min.	IS1206 (PARTII) [40] and ASTM D2171-07 [41]
Specific Gravity @25c	0.96	0.96	0.98	0.97	1.01-1.06	ASTM D70-18a [42]
Softening Point	60	54	58	57.3	55-65	BS EN 1427:2015 [43], IS:1205 [44] and ASTM D36-06 [45]
Flash Point	275	270	278	278	≥ 250	ISO 2592:2017 and ASTM D92-18 [47]
Loss on heating (%)	0.88	0.84	0.87	0.86	2%	IS:1212 [48]
Moisture Content (%)	0.0021	0.0024	0.0022	0.0022	0.2	IS:1211 [49]

2.2. Mix Design, Production and Testing

The experimental design was done using response surface methodology (RSM). All independent variables were varied simultaneously. The independent variables are coarse aggregate (CA), fine aggregate (FA), mineral filler (MF), bitumen content (BC), and cassava peel ash (CPA). Table 3 presents the independent variables and the range of variation, as given by the central composite design. The experimental plan designed was used to produce the bituminous mixtures using the Marshall Method for designing hot mix asphalt mixtures accordance with ASTM D1559-89 [50]. According to the standard 75-blow Marshal design method designated as a number of 10 samples each of 1200g in weight were prepared using the mix proportions shown in Table 4. As shown in Figure 2, Marshall Properties of the asphalt mix such as stability, flow, density, air voids in total mix, and voids filled with bitumen percentage were obtained for various mix constituents. The flowchart of the research methodology used to achieve the study is illustrated in Figure 3.

Table 3. Factors considered with their coded levels

Factors	Code	Unit	Coded levels		
			-1	0	+1
CA	A	%	46	49	52
FA	B	%	10	12	14
MF	C	%	15	17.5	20
BC	D	%	4	6	8
CPA	E	%	0	10	20

Note: CA=Coarse aggregate, FA=Fine aggregate, MF=Mineral filler, BC=Bitumen content, CPA=Cassava peel ash.

Table 4. Design of Experiment

Run	CA%	FA%	MF%	CB%	CPA%	CAg	Fag	MFg	CBg	CPAg
1	50.32	10	20	6.58	11.86	603.8	120	240	78.96	142.3
2	46	12.4	20	4	0	552	148.8	240	48	0
3	49.9	14	19.75	6.56	0	598.8	168	237	78.72	0
4	49	12	17.5	6	10	588	144	210	72	120
5	50.5	14	19.1	5.5	10.9	606	168	229.2	66	130.8
6	49	12	17.5	6	10	588	144	210	72	120
7	46.6	10.28	15	4	12.7	559.2	123.36	180	48	152.4
8	49	12	17.5	6	10	588	144	210	72	120
9	49.18	10	17.75	8	20	590.2	120	213	96	240
10	52	10	20	8	0	624	120	240	96	0
11	46	10	20	5.46	20	552	120	240	65.52	240
12	46	14	15	5.36	2.8	552	168	180	64.32	33.6
13	52	10	17.5	4	20	624	120	210	48	240
14	48.4	11.18	15	5.06	1.4	580.8	134.16	180	60.72	16.8
15	48.97	11.8	15	8	0	587.6	141.6	180	96	0
16	46	13.8	17.95	4	20	552	165.6	215.4	48	240
17	49	12	17.5	6	10	588	144	210	72	120
18	50.38	11.57	15.435	4	13.3	604.6	138.87	185.23	48	159.6
19	49	12	17.5	6	10	588	144	210	72	120
20	52	12.18	15.875	4	0	624	146.16	190.5	48	0
21	50.61	14	15	4.56	20	607.4	168	180	54.72	240
22	46	10	17.1	6.32	0	552	120	205.2	75.84	0
23	50.8	12.06	15	7.7	20	609.6	144.72	180	92.4	240
24	46	11.78	20	8	7.5	552	141.31	240	96	90
25	49.18	10	17.75	8	20	590.2	120	213	96	240
26	52	10	15	6.52	10	624	120	180	78.24	120
27	52	14	16.594	8	10	624	168	199.13	96	120
28	46	12.46	15	7.68	20	552	149.52	180	92.16	240
29	52	12.17	20	6.66	20	624	146.03	240	79.92	240
30	49.9	14	19.75	6.56	0	598.8	168	237	78.72	0
31	47.44	14	20	8	20	569.3	168	240	96	240
32	49.63	10	20	4	5.5	595.6	120	240	48	66

(a) (b) (c)

Figure 2. Marshall Properties (a) Marshall samples (b) Weight in air and water (c) Marshall machine

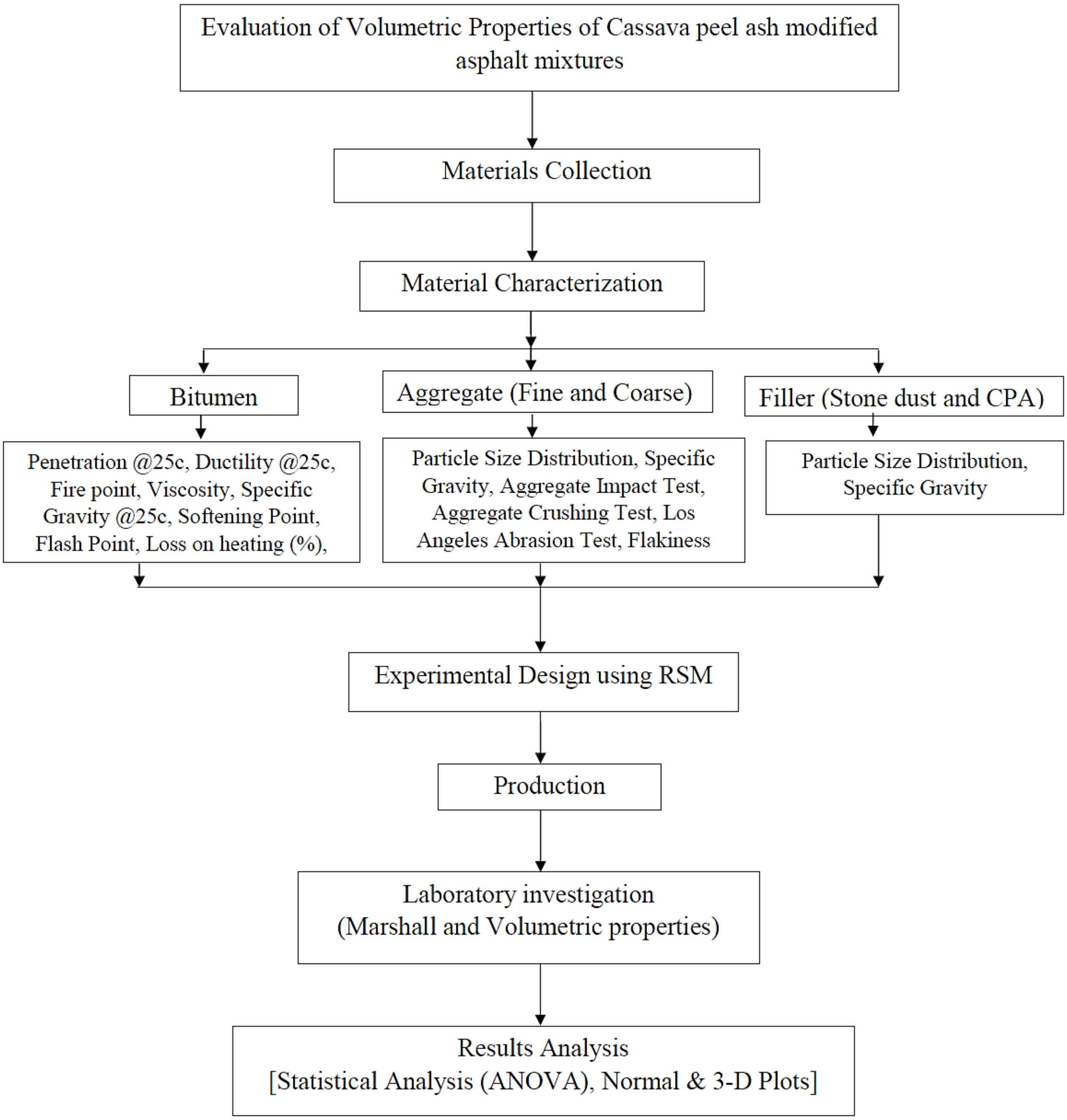


Figure 3. Research Methodology

3. Results and Discussion

3.1. Volumetric Properties Of CPA-Modified Asphalt Mixtures

The volumetric properties of CPA-modified asphalt mixtures are shown in Table 5. The Marshall stability, flow, density, volume of the void, and void in mineral aggregates of the asphalt mixtures varied 1.8037-8.045 kN, 2.7-8.22 mm, 2.0426-2.3909%, 1.094-7.966% and 55.5105-93.1393% respectively. These results are the effect of simultaneously varying factors such as coarse aggregate, fine aggregate, mineral filler, bitumen content, and cassava peel ash on the asphalt mixtures. From Table 5, the highest stability has 20% of CPA while the lowest stability has 10% CPA. However, in terms of the flow property of the CPA-modified mixtures, the highest flow was 8.22mm with 0% CPA, and the lowest of 2.7mm with a CPA of 13.7%. Also, the highest values of void in mineral aggregate (VMA) were observed at 10% CPA content, whereas the lowest VMA value was found at the highest CPA content. These results imply the role of CPA in the mixture in influencing the volumetric properties of the mixtures. Furthermore, it was observed that only run 16 and 15 (CA:46%, FA:13.8%, MF:17.95%, BC:4%, CPA:20% and CA:48.97%, FA:11.8%, MF:15%, BC:8%, CPA:0% respectively) with stability value of 8.045kN and 7.886kN are higher than the minimum stability value specified by ASTM A530/A530M-18 [51].

Table 5. Experimental results

Run	Factor A:CA	Factor B:FA	Factor C:MF	Factor D:BC	Factor E:CPA	Response 1 Marshall Stability (KN)	Response 2 Flow (mm)	Response 3 GM (%)	Response 4 VV (%)	Response 5: VMA (%)
1	50.32	10	20	6.58	11.86	4.76	2.8	2.24	2.43	86.24
2	46	12.4	20	4	0	2.38	4.35	2.25	2.29	82.93
3	49.9	14	19.75	6.56	0	5.26	4.43	2.20	2.22	87.99
4	49	12	17.5	6	10	6.32	4.1	2.20	5.056	73.82
5	52	14	20	4	10.9	7.29	5.58	2.32	2.87	76.58
6	49	12	17.5	6	10	2.36	5.55	2.23	3.83	79.02
7	46.6	10.28	15	4	12.7	6.83	6.43	2.32	3.82	73.62
8	49	12	17.5	6	10	1.80	6.22	2.22	4.11	77.77
9	49.18	10	17.75	8	20	6.39	4.90	2.25	2.47	87.64
10	52	10	20	8	0	6.43	3.80	2.14	2.44	88.79
11	46	10	20	5.46	20	4.91	5.82	2.25	4.57	73.01
12	46	14	15	5.36	2.8	3.60	3.55	2.12	7.97	63.64
13	52	10	17.5	4	20	4.88	4.20	2.29	6.19	59.37
14	48.4	11.18	15	5.06	1.4	5.91	3.12	2.13	7.50	64.46
15	48.97	11.8	15	8	0	7.89	3.30	2.04	7.13	73.62
16	46	13.8	17.95	4	20	8.05	4.18	2.25	7.24	55.51
17	49	12	17.5	6	10	6.35	3.60	2.29	1.09	93.14
18	50.38	11.57	15.44	4	13.3	7.45	2.70	2.29	5.41	64.61
19	49	12	17.5	6	10	4.76	3.68	2.20	5.22	73.18
20	52	12.18	15.88	4	0	4.62	6.75	2.23	5.34	66.95
21	50.61	14	15	4.56	20	4.93	4.7	2.39	2.11	83.52
22	46	10	17.1	6.32	0	4.82	8.22	2.11	4.97	77.54
23	50.8	12.06	15	7.7	20	6.10	5.28	2.22	5.11	76.37
24	46	11.78	20	8	7.5	5.60	5.45	2.13	3.70	83.46
25	49.18	10	17.75	8	20	5.61	5.43	2.21	4.06	80.87
26	52	10	15	6.52	10	6.05	4.43	2.24	3.68	81.23
27	52	14	16.59	8	10	5.58	4.18	2.11	7.25	70.27
28	46	12.46	15	7.68	20	5.41	3.50	2.23	3.96	81.35
29	52	12.17	20	6.66	20	4.11	3.25	2.22802	5.08	72.91
30	49.9	14	19.75	6.56	0	5.89	6.4	2.17076	3.04	84.13
31	47.44	14	20	8	20	4.39	4.7	2.19693	4.32	79.13
32	49.63	10	20	4	5.5	6.04	4.23	2.24611	4.22	70.90

3.2. Statistical Analysis

The RSM was used to obtain the interactions between the Outputs and the Independent variables from the ANOVA table, which displays the layout for experimental design and amounts for all of the responses with these values. For the responses, quadratic polynomial equations were created. The responses in the model are Coarse Aggregate (A), Fine Aggregate (B), Filler (C), Bitumen Content (D), and Cassava Peels (E). Checking the model's adequacy is a critical element of the data analysis because the model functions will produce incorrect responses if the fit is not good enough [52]. As a result, ANOVA analysis was used to determine the significance and applicability of models, and the findings are presented in Table 6. This table covers the various statistical variables as well as the quadratic models for coded factors. In this table, p-values<0.0001 shows that the model and variables are significant. In these tables p-values, less than 0.0001 imply that the model and parameter are significant (model and termp-values which are less than 0.0001 imply that the model and parameter are significant for 95% confidence intervals).

Table 6. ANOVA for responses

Source	Sum of Squares	df	Mean Square	F-value	p-value	Significance
			Marshal Stability			
Model	43.44	20	2.17	96.48	< 0.0001	significant
A	0.1572	1	0.1572	6.98	0.0229	
B	1.45	1	1.45	64.62	< 0.0001	
C	3.40	1	3.40	150.93	<0.0001	
D	0.2732	1	0.2732	12.14	0.0051	
E	0.4502	1	0.4502	20.00	0.0009	
AB	0.9115	1	0.9115	40.49	<0.0001	
AC	0.5118	1	0.5118	22.74	0.0006	
AD	0.1129	1	0.1129	5.02	0.0467	
AE	3.53	1	3.53	156.74	<0.0001	
BC	4.67	1	4.67	207.25	<0.0001	
BD	2.53	1	2.53	112.42	<0.0001	
BE	0.0037	1	0.0037	0.1665	0.6911	
CD	1.64	1	1.64	72.92	<0.0001	
CE	0.4091	1	0.4091	18.17	0.0013	
DE	9.73	1	9.73	432.22	<0.0001	
A^2	1.81	1	1.81	80.19	<0.0001	
B^2	0.6136	1	0.6136	27.26	0.0003	
C^2	2.05	1	2.05	91.08	<0.0001	
D^2	10.65	1	10.65	473.27	<0.0001	
E^2	0.1071	1	0.1071	4.76	0.0518	
Residual	0.2476	11	0.0225			
Lack of Fit	0.1255	5	0.0251	1.23	0.3968	Not significant
Pure Error	0.1221	6	0.0203			
R^2	0.9943					
Adjusted R^2	0.9840					
Predicted R^2	0.8912					
Cor Total	43.68	31				
			Flow			
Model	31.31	20	1.57	108.38	<0.0001	significant
A-CA	1.05	1	1.05	72.42	<0.0001	
B-FA	2.47	1	2.47	171.11	<0.0001	
C-MF	0.0025	1	0.0025	0.1762	0.6828	
D-CB	0.2234	1	0.2234	15.47	0.0023	
E-CPA	1.09	1	1.09	75.25	<0.0001	
AB	11.14	1	11.14	771.23	<0.0001	
AC	1.08	1	1.08	75.06	<0.0001	
AD	0.4190	1	0.4190	29.01	0.0002	
AE	0.1436	1	0.1436	9.94	0.0092	
BC	3.96	1	3.96	274.31	<0.0001	
BD	0.3436	1	0.3436	23.79	0.0005	
BE	0.3450	1	0.3450	23.89	0.0005	
CD	1.09	1	1.09	75.35	<0.0001	
CE	1.41	1	1.41	97.86	<0.0001	
DE	1.29	1	1.29	89.66	<0.0001	
A^2	1.72	1	1.72	119.38	<0.0001	
B^2	1.42	1	1.42	98.66	<0.0001	
C^2	3.68	1	3.68	254.55	<0.0001	
D^2	0.7640	1	0.7640	52.90	<0.0001	
E^2	1.07	1	1.07	74.07	<0.0001	

Residual	0.1589	11	0.0144			
Lack of Fit	0.0882	5	0.0176	1.50	0.3159	not significant
Pure Error	0.0706	6	0.0118			
R^2	0.9950					
Adjusted R^2	0.9858					
Predicted R^2	0.9024					
Cor Total	31.46	31				
			GM			
Model	0.1513	20	0.0076	17.86	<0.0001	significant
A-CA	0.0028	1	0.0028	6.58	0.0263	
B-FA	0.0007	1	0.0007	1.77	0.2105	
C-MF	0.0011	1	0.0011	2.68	0.1302	
D-CB	0.0662	1	0.0662	156.30	<0.0001	
E-CPA	0.0602	1	0.0602	141.99	<0.0001	
AB	0.0010	1	0.0010	2.40	0.1492	
AC	0.0001	1	0.0001	0.3006	0.5945	
AD	0.0009	1	0.0009	2.20	0.1660	
AE	0.0007	1	0.0007	1.55	0.2389	
BC	0.0008	1	0.0008	1.99	0.1862	
BD	0.0030	1	0.0030	7.12	0.0219	
BE	0.0001	1	0.0001	0.1309	0.7244	
CD	0.0021	1	0.0021	4.92	0.0485	
CE	0.0161	1	0.0161	37.88	<0.0001	
DE	0.0018	1	0.0018	4.34	0.0613	
A^2	0.0018	1	0.0018	4.32	0.0620	
B^2	0.0000	1	0.0000	0.0333	0.8585	
C^2	0.0010	1	0.0010	2.38	0.1513	
D^2	0.0022	1	0.0022	5.27	0.0424	
E^2	0.0021	1	0.0021	4.93	0.0484	
Residual	0.0047	11	0.0004			
Lack of Fit	0.0006	5	0.0001	0.1641	0.9670	not significant
Pure Error	0.0041	6	0.0007			
R^2	0.9701					
Adjusted R^2	0.9158					
Predicted R^2	0.8357					
Cor Total	0.1560	31				

All of the models proposed in this study are statistically significant, with p-values less than 0.05. However, for each response, a few unimportant interactions (p-value>0.100) were identified and specified. As a result, these irrelevant terms can be removed from the model to improve the model and maximize the result [53]. To check the fitness of the model regression coefficients R^2 and adjusted R^2 were calculated. The R^2 and adjR^2 values indicate that there is a good agreement between predicted and actual values [54]. Adequacy can be attained from AP value when AP>4 for all responses presented in all ANOVA Table 6. This supports that the model can be used to navigate the design space defined by CCD.

Final Equation for Stability = $4.39182 + 0.104228A + -0.308408B + -0.434318C + 0.13329D + 0.166102E + 0.309765AB + 0.217852AC + 0.109551AD + -0.597931AE + 0.673579BC + -0.515239BD + 0.019301BE + -0.389932CD + 0.188267CE + -1.00632DE + -0.591076A^2 + 0.336639B^2 + 0.61323C^2 + 1.46511D^2 + -0.139121E^2$ (1)

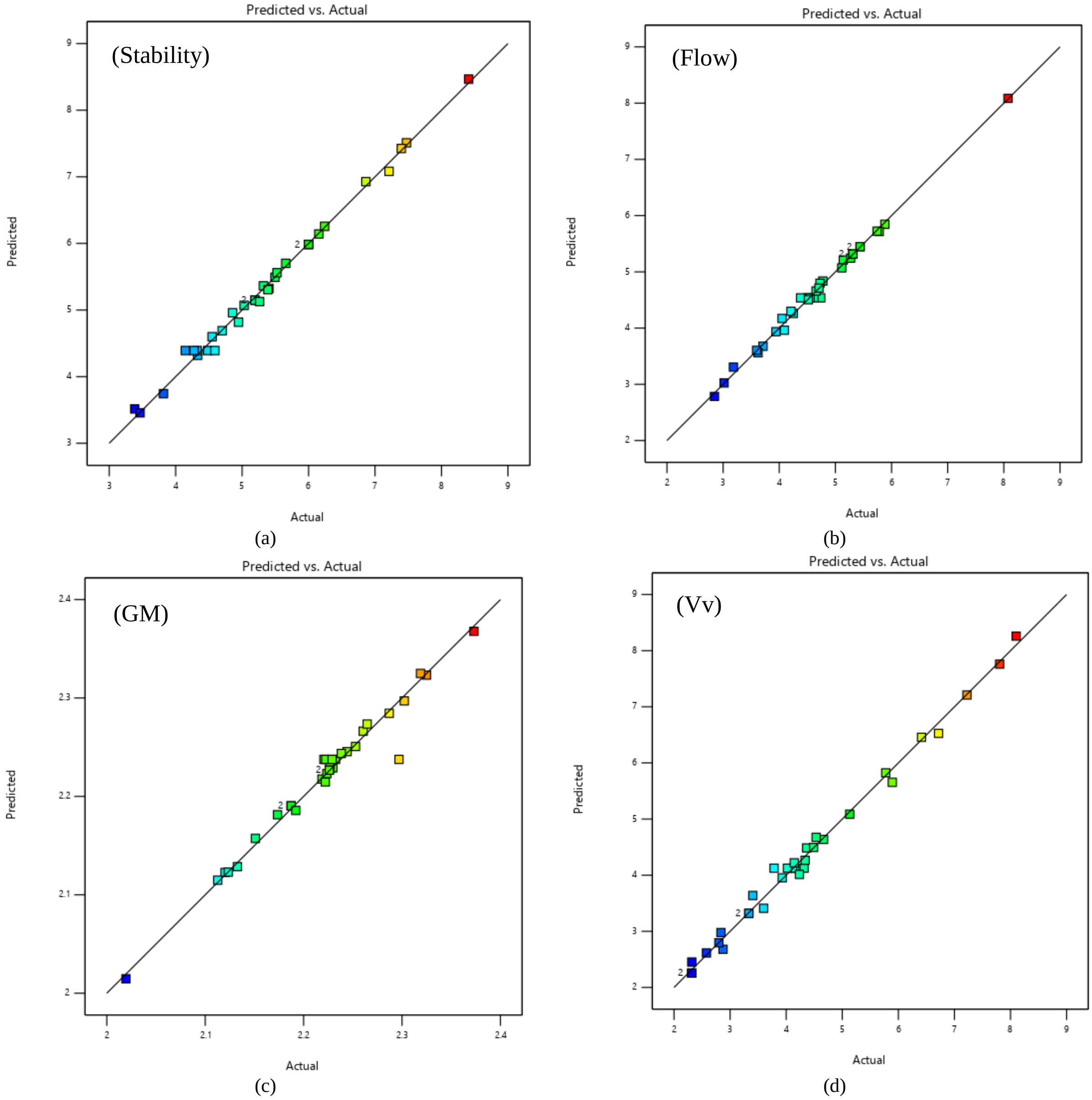
Final Equation for Flow = $4.53706 - 0.268815A - 0.40198B - 0.011885C - 0.120517D - 0.258087E + 1.08286AB - 0.317057AC - 0.211031AD - 0.120611AE + 0.620707BC - 0.189844BD + 0.1852BE\ 0.317497CD - 0.349926CE + 0.367116DE + 0.577661A^2 + 0.513004B^2 - 0.821152C^2 - 0.392334D^2 + 0.439789E^2$ (2)

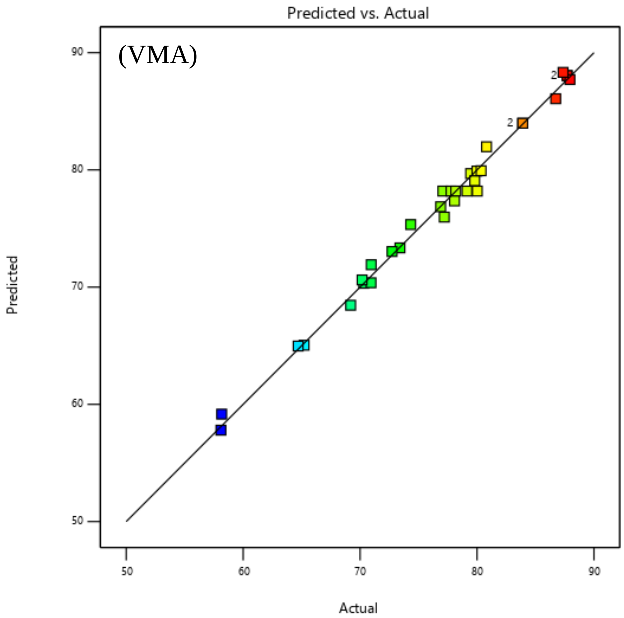
Final equation for GM = $2.23757 + 0.0138803A - 0.00699992B + 0.00793359C - 0.0656211D + 0.0607209E + 0.0103568AB + -0.00343675AC - 0.00995737AD - 0.00816008AE + 0.00905097BC - 0.0177908BD + 0.00234758BE + 0.0138951CD - 0.0372899CE + 0.0138365DE - 0.0188114A^2 + 0.00161444B^2 + 0.0135948C^2 - 0.0212056D^2 - 0.0194288E^2$ (3)

3.3. Response Surface Methodology (RSM)

3.3.1. Normality and 3-D Plot

The one factor at a time (OFAT) technique is a well-known strategy for optimizing multifactor tests. For a certain experimental design, OFAT comprises a single variable that may be changed while the other parameters remain constant. OFAT is unable to produce suitable results since the effects of interactions among all relevant components in the designs are not thoroughly studied, and it is incapable of achieving the genuine optimal value. As a result, the RSM technique was established for parameter optimization to reduce the number of tests and parameter interactions to a minimum [52, 54-58]. This depicts the normal probability plots of both residuals and the actual versus predicted for hot mix asphaltic concrete HMA containing CPA. The experimental data obtained with the mixing process was analyzed using the Design expert software [59]. The influence of all the independent factors on the stability, flow, Volume of voids (Vv), GM, and VMA of Asphalt concrete composite was studied. Knowing model satisfactoriness is critical, and understanding diagnostic charts such as projected versus actual values can help. Figures 4(a-e) show that the plotted point falls either on or close to the distributed line of the plot.





(e)

Figure 4. Normality plot; predicted vs. actual

The 3-D plots for stability are observed in Figures 5 to 14. The effect of FA and CA on the stability of the asphaltic concrete while holding MF, CB, and CPA at a constant (center) point is shown in Figure 5. As it could be seen from the plot, FA had a linear effect on the response (stability) while CA had a quadratic effect on the response. On the individual effect of the independent variable on the response, it could be seen that an increase in FA at low CA resulted in a decrease in the stability of the asphaltic concrete. On the other hand, an increase in CA up to 51.21% resulted in a slight increase in the stability of the asphaltic concrete, however, increasing the percentage CA above 51.21% caused a significant decrease in the stability of the concrete. A combined effect of the independent variables revealed an increase in both the percentage of FA and CA led to a decrease in the marshal stability of the concrete. For maximum marshal stability, the percentage should be held at a lower level (9.5%) while the CA is set at 49%. The effect of CA and MF on the marshal stability of the concrete while holding other independent variables (FA, CB, and CPA) at a constant level is shown in Figure 6. The percentage CA had a quadratic effect on the response while the MF had a linear effect on the response. An increase in the percentage MF resulted in a slight decrease in the marshal stability of the concrete. An increase in the percentage of CA on the other hand led to an initial increase in the MS, however, an increase in the percentage of CA above 51.21% resulted in a slight decrease in the MS of the concrete. When the percentage MF is set at the barest minimum and the percentage CA is set at 49.03%, the maximum marshal stability of the concrete is achieved.

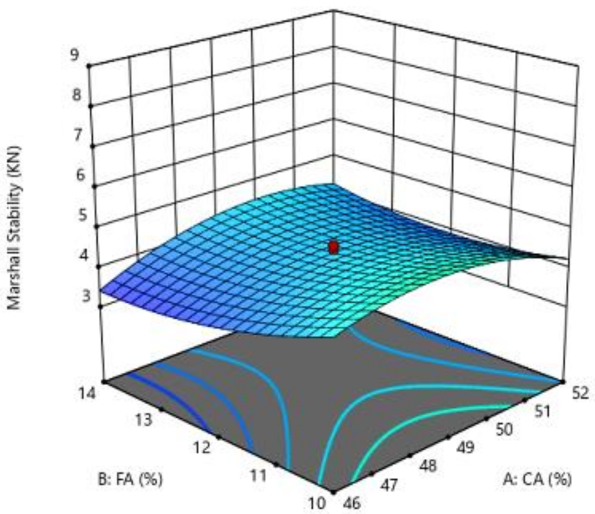


Figure 5. Effect of FA and CA on Stability

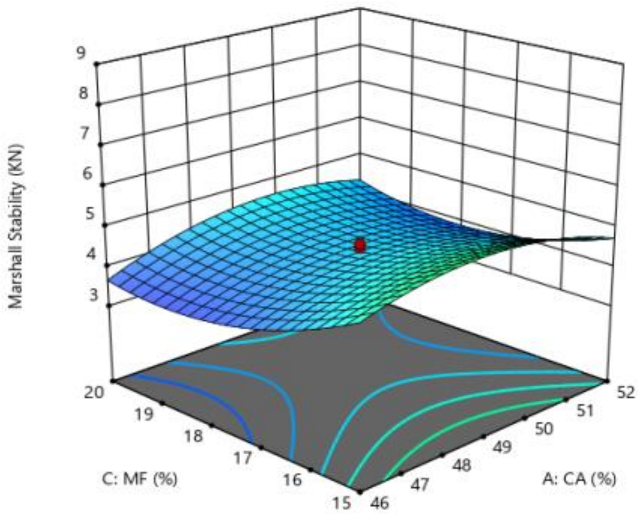


Figure 6. Effect of Filler and CA on Stability

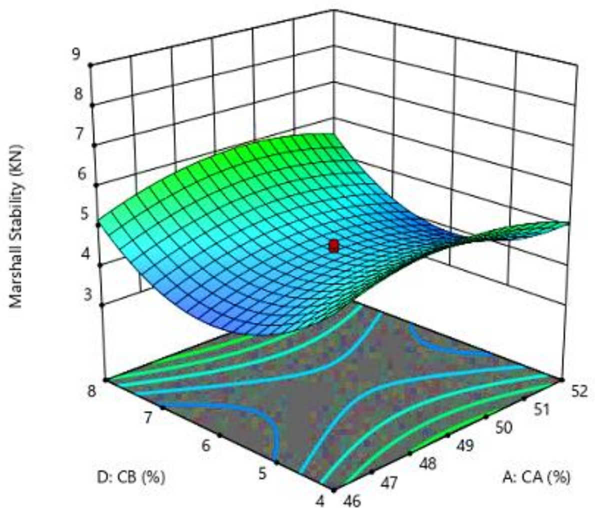


Figure 7. Effect of Bitumen content and CA on Stability

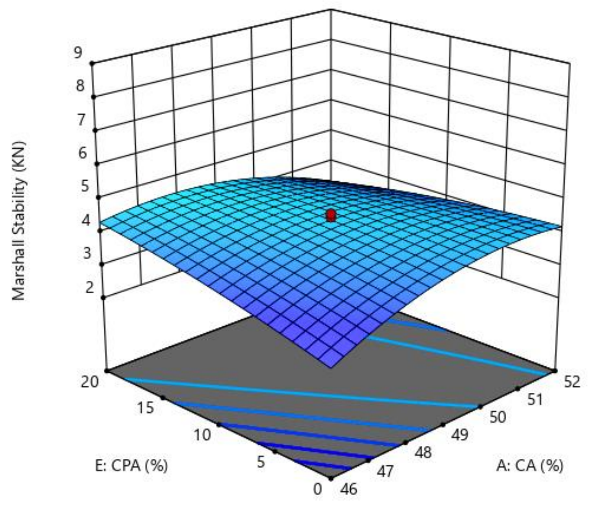


Figure 8. Effect of CPA and CA on Stability

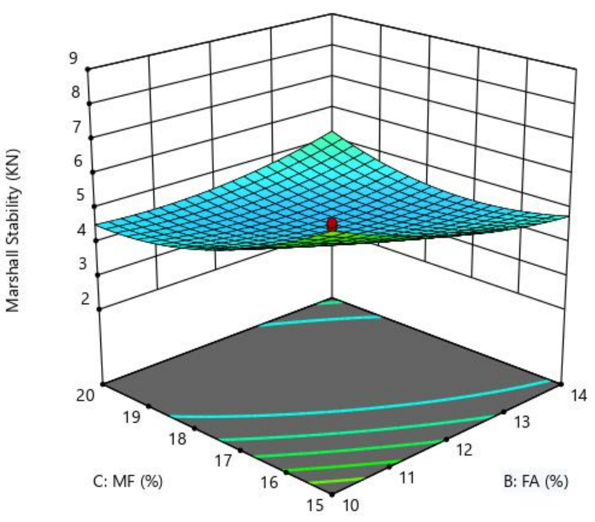


Figure 9. Effect of MF and FA on marshal Stability

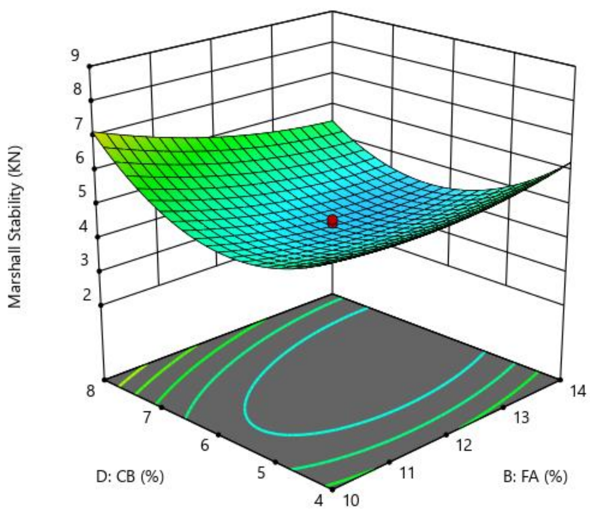


Figure 10. Effect of CB and FA on Stability

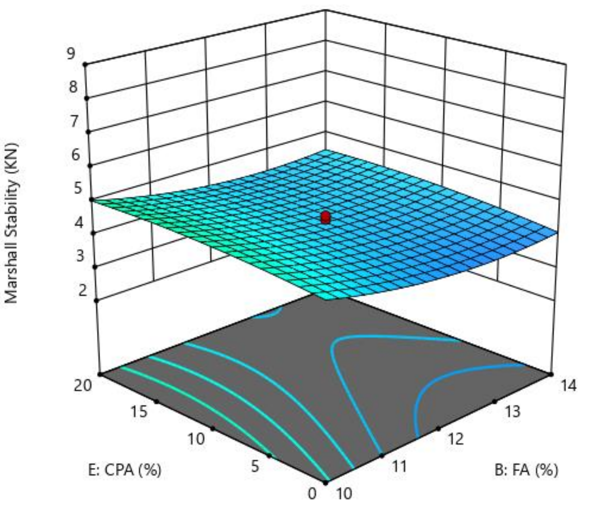


Figure 11. Effect of CPA and FA on Stability

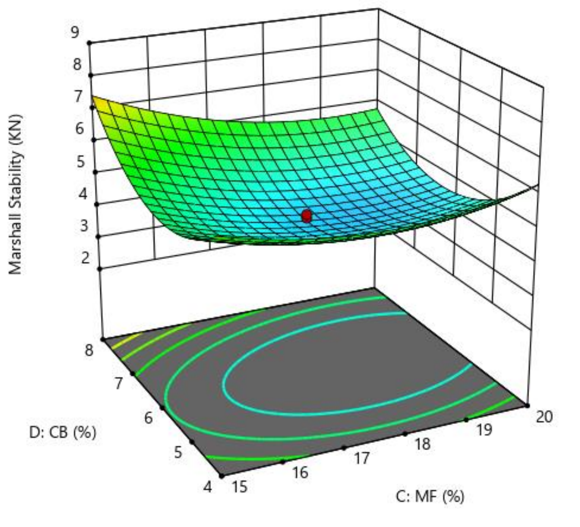


Figure 12. Effect of CB and MF on Marshal Stability

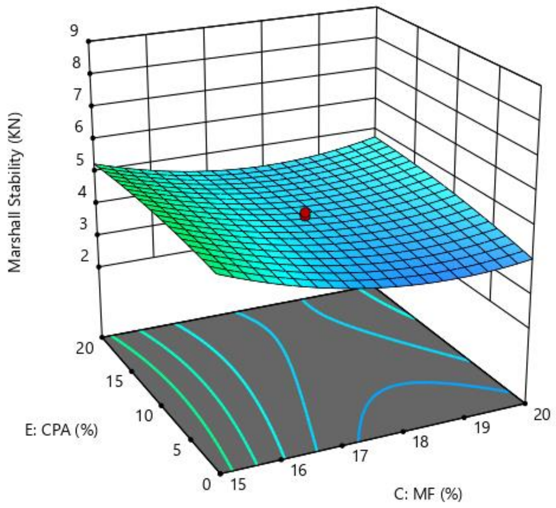


Figure 13. Effect of CPA and Mineral Filler on stability

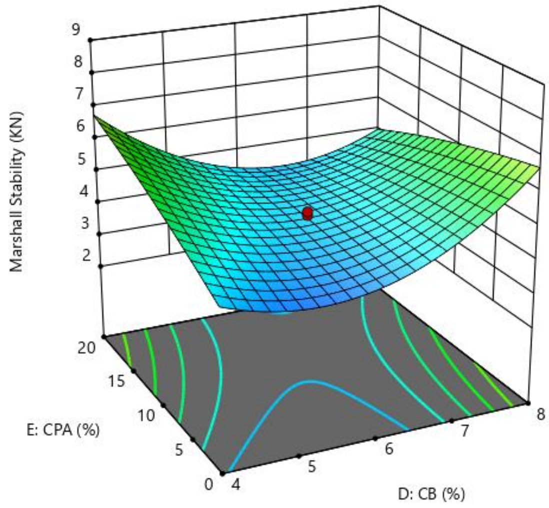


Figure 14. Effect of CPA and CB on Stability

4. Conclusions

Numerous techniques can be employed to lessen pavement discomfort and increase the lifespan of the surface. However, one of the most effective remedies for pavement deterioration is thought to be a modified asphalt mixture. This study aimed to evaluate the volumetric properties of CPA-modified asphalt mixtures. Response surface methodology was utilized in this study to find the interactions between selected parameters. Based on the results achieved in this study, the following conclusions are drawn:

- Higher stability was obtained from mixtures having a high asphalt content not less than and CPA value not less than 10%;
- When the percentage MF is set at the barest minimum and the percentage CA is set at 49.03%, the maximum marshal stability of the concrete is achieved;
- Based on the results achieved from RSM analysis, amounts of 4.018% asphalt content, 20% cassava peel ash, 46% coarse aggregate, 10% fine aggregate, and 15% mineral filler give the optimal asphalt content;
- Good agreement was found between predicted and actual values which indicated that suggested models could successfully predict mixture properties within the range of defined factors, hence, the use of RSM can be utilized in place of the Marshall design method;
- CPA showed good material as filler for asphalt mixtures meeting all volumetric conditions, therefore it can be used as a conventional material in the production of asphaltic concrete/pavement design. Subsequent research should use RSM for optimization in different test conditions;
- In order to fully understand the implications of the findings of this work, it will be critical to consider the other properties of CPA-modified asphalt mixtures, such as fatigue.

5. Declarations

5.1. Author Contributions

Conceptualization, O.J.A. , O.D.O. and T.E.D.; methodology, O.J.A., T.E.D., E.A. and P.C.C.; software, O.D.O. and T.E.D.; validation, O.D.O., E.A., and O.J.A.; formal analysis, O.D.O. and O.J.A.; investigation, T.E.D. and O.J.A.; resources, T.E.D. and P.N.; data curation, T.E.D.; writing—original draft preparation, E.A. and O.D.O. ; writing—review and editing, E.A., O.D.O. and P.C.C.; visualization, P.N; supervision, O.J.A. and T.E.D.; project administration, T.E.D. and O.J.A.; funding acquisition, P.C.C. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Plati, C., & Cliatt, B. (2019). A sustainability perspective for unbound reclaimed asphalt pavement (RAP) as a pavement base material. Sustainability (Switzerland), 11(1), 1–17. doi:10.3390/su11010078.

[2] Modupe, A. E., Fadugba, O. G., Busari, A. A., Adeboje, A. O., Aladegboye, O. J., Alejolowo, O. O., & Chukwuma, C. G. (2021). Sustainability Assessment of the Engineering Properties of Asphalt Concrete Incorporating Pulverized Snail Shell Ash as Partial Replacement for Filler. IOP Conference Series: Earth and Environmental Science, 665(1), 12057. doi:10.1088/1755-1315/665/1/012057.

[3] Graham, L. A. (2018). Pavement Preservation Best Practices Technical Briefs. Ph.D. Thesis, University of Nevada, Reno, United States.

[4] Lee, K. W., & Mahboub, K. C. (2006). Asphalt mix design and construction: Past, present, and future. The Bituminous Material Committee of the Construction Institute of ASCE, A special publication for the 150th Anniversary of ASCE. doi:10.1061/9780784408421.

[5] Eswan, E., Adisasmita, S. A., Ramli, M. I., & Rauf, S. (2021). Characteristics of Asphalt Mixed Using Mountain Stone. Civil Engineering Journal, 7(2), 268-277. doi:10.28991/cej-2021-03091652.

[6] Chen, M., Lin, J., & Wu, S. (2011). Potential of recycled fine aggregates powder as filler in asphalt mixture. Construction and Building Materials, 25(10), 3909–3914. doi:10.1016/j.conbuildmat.2011.04.022.

[7] Chen, J.-S., Kuo, P.-H., Lin, P.-S., Huang, C.-C., & Lin, K.-Y. (2007). Experimental and theoretical characterization of the engineering behavior of bitumen mixed with mineral filler. Materials and Structures, 41(6), 1015–1024. doi:10.1617/s11527-007-9302-5.

[8] Abtahi, S. M., Sheikhzadeh, M., & Hejazi, S. M. (2010). Fiber-reinforced asphalt-concrete – A review. Construction and Building Materials, 24(6), 871–877. doi:10.1016/j.conbuildmat.2009.11.009.

[9] Kalantar, Z. N., Karim, M. R., & Mahrez, A. (2012). A review of using waste and virgin polymer in pavement. Construction and Building Materials, 33, 55–62. doi:10.1016/j.conbuildmat.2012.01.009.

[10] Huang, Y., Bird, R. N., & Heidrich, O. (2007). A review of the use of recycled solid waste materials in asphalt pavements. Resources, Conservation and Recycling, 52(1), 58–73. doi:10.1016/j.resconrec.2007.02.002.

[11] Shu, X., & Huang, B. (2014). Recycling of waste tire rubber in asphalt and Portland cement concrete: An overview. Construction and Building Materials, 67, 217–224. doi:10.1016/j.conbuildmat.2013.11.027.

[12] Al-Hdabi, A. (2016). Laboratory investigation on the properties of asphalt concrete mixture with Rice Husk Ash as filler. Construction and Building Materials, 126, 544–551. doi:10.1016/j.conbuildmat.2016.09.070.

[13] Bi, Y., & Jakarni, F. (2019). Evaluating properties of wood ash modified asphalt mixtures. IOP Conference Series: Materials Science and Engineering, 512, 012004. doi:10.1088/1757-899x/512/1/012004.

[14] Modupe, A. E., Olayanju, T. M. A., Atoyebi, O. D., Aladegboye, S. J., Awolusi, T. F., Busari, A. A., Aderemi, P. O., & Modupe, O. C. (2019). Performance evaluation of hot mix asphaltic concrete incorporating cow bone ash (CBA) as partial replacement for filler. IOP Conference Series: Materials Science and Engineering, 640(1). doi:10.1088/1757-899X/640/1/012082.

[15] Adesanya, D. A., & Raheem, A. A. (2009). Development of corn cob ash blended cement. Construction and Building Materials, 23(1), 347–352. doi:10.1016/j.conbuildmat.2007.11.013.

[16] Oluwatuyi, O. E., Adeola, B. O., Alhassan, E. A., Nnochiri, E. S., Modupe, A. E., Elemile, O. O., Obayanju, T., & Akerele, G. (2018). Ameliorating effect of milled eggshell on cement stabilized lateritic soil for highway construction. Case Studies in Construction Materials, 9, e00191. doi:10.1016/j.cscm.2018.e00191.

[17] Adesanya, O. A., Oluyemi, K. A., Josiah, S. J., Adesanya, R., Shittu, L., Ofusori, D., ... & Babalola, G. (2008). Ethanol production by Saccharomyces cerevisiae from cassava peel hydrolysate. The Internet Journal of Microbiology, 5(1), 25-35. doi:10.5580/4f1.

[18] Adegoke, D. D., Ogundairo, T. O., Olukanni, D. O., & Olofinnade, O. M. (2019). Application of Recycled Waste Materials for Highway Construction: Prospect and Challenges. Journal of Physics: Conference Series, 1378(2), 22058. doi:10.1088/1742-6596/1378/2/022058.

[19] Ayodele, A. L., Mgboh, C. V, & Fajobi, A. B. (2021). Geotechnical properties of some selected lateritic soils stabilized with cassava peel ash and lime. Algerian Journal of Engineering and Technology, 04, 22–29. doi:10.5281/zenodo.4536448.

[20] Raheem, Arubike, E. D., & Awogboro, O. S. (2015). Effects of Cassava Peel Ash (CPA) as Alternative Binder in Concrete. International Journal of Constructive Research in Civil Engineering, 1(2), 27–32.

[21] Olatokunbo, O., Anthony, E., Rotimi, O., Solomon, O., Tolulope, A., John, O., & Adeoye, O. (2018). Assessment of strength properties of cassava peel ash-concrete. International Journal of Civil Engineering and Technology, 9(1), 965-974.

[22] Osuide, E. E., Ukeme, U., & Osuide, M. O. (2021). An assessment of the compressive strength of concrete made with cement partially replaced with cassava peel ash. SAU Science-Tech Journal, 6(1), 64-73.

[23] Olubunmi A, A., Taiye J., A., & Tobi, A. (2022). Compressive Strength Properties of Cassava Peel Ash and Wood Ash in Concrete Production. International Journal of New Practices in Management and Engineering, 11(01), 31–40. doi:10.17762/ijnpme.v11i01.171.

[24] Ogunbode, E. B., Nyakuma, B. B., Jimoh, R. A., Lawal, T. A., & Nmadu, H. G. (2021). Mechanical and microstructure properties of cassava peel ash–based Kenaf bio-fibrous concrete composites. Biomass Conversion and Biorefinery, 2021, 1–11. doi:10.1007/s13399-021-01588-6.

[25] Tang, Z., Li, Z., Hua, J., Lu, S., & Chi, L. (2022). Enhancing the damping properties of cement mortar by pre-treating coconut fibers for weakened interfaces. Journal of Cleaner Production, 134662. doi:10.1016/j.jclepro.2022.134662.

[26] Salau, M. A., & Olonade, K. A. (2011). Pozzolanic potentials of cassava peel ash. Journal of Engineering Research, 16(1), 10-21.

[27] Ubalua, A. O. (2007). Cassava wastes: Treatment options and value addition alternatives. African Journal of Biotechnology, 6(18), 2065–2073. doi:10.5897/ajb2007.000-2319.

[28] ASTM D2487-17. (2020). Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). ASTM International, Pennsylvania, United States. doi:10.1520/D2487-17.

[29] ASTM C127-15. (2016). Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregates. ASTM International, Pennsylvania, United States. doi:10.1520/C0127-15.

[30] ASTM D5874-16. (2016). Standard Test Methods for Determination of the Impact Value (IV) of a Soil. ASTM International, Pennsylvania, United States. doi:10.1520/D5874-16.

[31] ASTM C131-06. (2010). Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine. ASTM International, Pennsylvania, United States. doi:10.1520/C0131-06.

[32] ASTM C128-15. (2016). Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregates. ASTM International, Pennsylvania, United States. doi:10.1520/C0128-15.

[33] ASTM D4719-20. (2020). Standard Test Methods for Prebored Pressuremeter Testing in Soils. ASTM International, Pennsylvania, United States. doi:10.1520/D4719-20.

[34] EN 1426:2015. (2015). Bitumen and bituminous binders. Determination of needle penetration. British Standard Institute (BSI), London, United Kingdom.

[35] IS:1203. (1978). Methods for Testing Tar and Bituminous Materials: Determination of Penetration. Bureau of Indian Standard, New Delhi, India.

[36] AASHTO D-5 (1993). AASHTO Guide for Design of Pavement Structures. American Association of State Highway and Transportation Officials, Vol. 1, Washington, United States.

[37] IS:1208. (1978). Methods for Testing Tar and Bituminous Materials: Determination of ductility. Bureau of Indian Standard, New Delhi, India.

[38] ASTM D113-99. (2010). Standard Test Method for Ductility of Bituminous Materials. ASTM International, Pennsylvania, United States. doi:10.1520/D0133-99.

[39] IS:1209. (1978). Methods for Testing Tar and Bituminous Materials: determination of Flash Point and Fire Point. Bureau of Indian Standard, New Delhi, India.

[40] IS:1206 (Part II). (1978). Methods for Testing Tar and Bituminous Materials: Determination of Viscosity. Bureau of Indian Standard, New Delhi, India.

[41] ASTM D2171-07. (2010). Standard Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer. ASTM International, Pennsylvania, United States. doi:10.1520/D2171-07.

[42] ASTM D70-18a. (2021). Standard Test Method for Density of Semi Solid Bituminous Materials (Pycnometer Method). ASTM International, Pennsylvania, United States. doi:10.1520/D0070-18A.

[43] BS EN 1427:2015. (2015). Bitumen and bituminous binders. Determination of the softening point. Ring and Ball Method. British Standards Institution (BSI), London, United Kingdom.

[44] IS:1205. (1978). Methods for Testing Tar and Bituminous Materials: determination of Softening Point. Bureau of Indian Standard, New Delhi, India.

[45] ASTM D36-06. (2010). Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus). ASTM International, Pennsylvania, United States. doi:10.1520/D0036-06.

[46] ISO 2592:2017. (2017). Petroleum and related products-Determination of flash and fire points-Cleveland open cup method. International Organization for Standardization (ISO), Geneva, Switzerland.

[47] ASTM D92-18. (2018). Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester. ASTM International, Pennsylvania, United States. doi:10.1520/D0092-18.

[48] IS:1212. (1978). Methods for Testing Tar and Bituminous Materials: Determination of Loss on Heating. Bureau of Indian Standard, New Delhi, India.

[49] IS:1211. (1978). Methods for Testing Tar and Bituminous Materials: Determination of Water Content (Dead and Stark Method). Bureau of Indian Standard, New Delhi, India.

[50] ASTM-D1559. (1989). Test Method for resistance of plastic flow of Bituminous Mixtures Using Marshal Apparatus (Withdrawn 1998). ASTM International, Pennsylvania, United States.

[51] ASTM A530/A530M-18. (2020). Standard Specification for General Requirements for Specialized Carbon and Alloy Steel Pipe. ASTM International, Pennsylvania, United States. doi:10.1520/A0530_A0530M-18

[52] Myers H. R., Montgomery, D. C., & Anderson-Cook, C. A. (2016). Response Surface Methodology: Process and Product Optimization Using designed Experiments (3rd Ed.). Wiley, Hoboken, United States.

[53] Hosseinpour, V., Kazemeini, M., & Mohammadrezaee, A. (2011). A study of the water-gas shift reaction in Ru-promoted Ir-catalysed methanol carbonylation utilizing experimental design methodology. Chemical Engineering Science, 66(20), 4798–4806. doi:10.1016/j.ces.2011.06.053.

[54] Azargohar, R., & Dalai, A. K. (2005). Production of activated carbon from Luscar char: Experimental and modeling studies. Microporous and Mesoporous Materials, 85(3), 219–225. doi:10.1016/j.micromeso.2005.06.018.

[55] Frigon, N. L., & Mathews, D. (1996). Practical guide to experimental design. John Wiley & Sons, Hoboken, United States.

[56] Khuri, A. I., & Cornell, J. A. (1996). Response Surfaces: Designs and Analyses (2nd Ed.). Marcel Dekker Inc., New York, United States.

[57] Obinna, A. C., Mbah, G. O., & Onoh, M. I. (2021). Optimization and Process Modelling of Viscosity of Oil Based Drilling Muds. Journal of Human, Earth, and Future, 2(4), 412-423. doi:10.28991/HEF-2021-02-04-09.

[58] Montgomery, D. C. (2005). Design and Analysis of Experiments (6th Ed.). John Wiley and Sons, New York, United States.

[59] Design-Expert software, v9, user's guide (2013). Technical manual, Stat Ease Inc. Minneapolis, United States. Available online: http://www.statease.com/dx9.html (accessed on August 2022).