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# Performance evaluation of hot mix asphaltic concrete incorporating cow bone ash (CBA) as partial replacement for filler

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**Abstract:** Given the current realities of incessant pavement distresses frequently experienced on Nigerian highways due to axle loads from heavy-duty vehicles, coupled with the menace of grave environmental pollution from abattoir solid wastes such as Cow-bones, the mechanistic properties of Cow Bone Ash (CBA) as partial replacement for filler in the production of asphaltic concrete via the Marshall Mix Design Method and Artificial Neural Networks (ANN) were investigated in this research. The conventional filler was partially replaced with CBA at 2.5%, 5%, 7.5%, 10%, 20%, 30%, 40% and 50% respectively, in the total mix. Sequel to the production of the bituminous concrete at the various proportions, the samples were submerged in water, in a water bath for 30 minutes at a temperature of 105°C before conducting Marshall Stability and flow tests. Results revealed that the stability and flow of asphaltic concrete containing the CBA were greater than that of the concrete containing the conventional filler. Furthermore, the physical and volumetric properties of the mix also improved as CBA was observed to be finer than the conventional quarry dust, hence reduced the voids present in the mix and stiffened the bitumen film on the aggregate particles. The results obtained further showed that the conventional filler (quarry dust) can be replaced partially with CBA up to 50%. The ANN Model employed was trained and tested by quick propagation (QP) algorithm amongst others such as the Incremental Back Propagation (IBP), Batch Back Propagation (BBP), Levenberg Marquardt (quasi Newton) and genetic algorithm (GA). QP gave the least Root Mean Square Error (RMSE) at the shortest time. The statistical values obtained showed that the ANN model was able to efficiently study and predict the experimental data.

**Keywords:** Pavement Engineering, Cow Bone Ash, Marshall Stability, Flow, Optimum Bitumen Content (OBC), Sustainable Pavements, ANN Model.

## 1. Introduction

Asphaltic concrete, owing to its superior in-service performance and capacity to provide driving comfort, stability, resilience and resistance to water, has been the most extensively used conventional material in the construction of flexible pavements [1]. Flexible pavement, also known as asphalt pavement is designed using a dense combination of asphalt (or bitumen), coarse and fine aggregates, and mineral filler [2]. This aggregate blend determines the final mechanical properties of the asphalt pavement. In bituminous pavement mixes, the mineral filler is the finest aggregate portion which mostly passes through a particle gradation sieve (generally known to be of size 0.075 mm size in India and 0.063 mm in Europe); and materials such as stone dust, hydrated lime and Ordinary Portland Cement (OPC) are conventionally used as fillers [3]. Mineral fillers tend to stiffen the asphalt cement by dispersing the fine materials in it [1]. Furthermore, they play a dual role in bituminous mixes; coarser particles of fillers act as inactive components and seal apertures



between larger mix aggregates, providing them with the required waterproofness and strength. However, particles of fillers that are finer and have smaller sizes than bitumen film thickness often play an important role in the viscosity and consistency modification of bitumen-filler mortars [3].

The incessant and pressing demand for transportation, leading to high volume of traffic on roads in urban centres is currently a challenge on future flexible pavement design and construction in most developing countries[4] and in Nigeria. This continuous increase with attendant axle loads, has triggered an accelerated and continuous deterioration of the main express highway pavements [5]. Besides, the increasing traffic volumes coupled with the upsurge in permissible axial loads have necessitated the improvement of the road paving materials [6], through the use of cost-effective construction materials and methods as well as the development of an improved and innovative roadway design [7]. Due to the high cost of the conventional fillers such as cement, lime and limestone dust which are utilized as main materials for other construction purposes, improving the engineering properties of asphaltic concrete mixtures through the use of cost-effective and alternative waste materials in road construction has become a common practice in the asphalt industry and also shown to improve pavement structure performance[8] in the wake of their increased usage. Similarly, all over the world, population and industrial growth have resulted in massive upsurge in the generation of a lot of wastes [9]. Most of the waste materials are either non-degradable such as scrap tires, waste plastics, synthetic polymers, tire tubes, brake pad waste, carbon powder, steel slag, copper tailings etc.,[10] or degradable wastes such as, egg shells, snail shells, sugarcane bagasse, cassava starch[11] and cow bones from abattoir wastes.

Interestingly, some alternative fillers from the non-degradable wastes have been investigated in asphaltic concrete mixtures by various researchers. For example amorphous carbon filler [12], oil shale powder [13], brake pad waste powder [14], carbon powder [15], recycled brick powder [16], alkali-activated binary blended cementitious filler [17], coal gangue [18], fly ash [19] lime kiln dust [20], and steel slag [2] have been utilized as filler partially in bituminous mixtures. Each material had significant positive influence on the engineering properties of the modified mixes. Similarly, research efforts have also been focused on the use of degradable waste materials, especially from agriculture as filler in asphaltic concrete mixtures. In Nigeria, wastes from abattoir or slaughter-houses are beginning to pose as threat and grave environmental concern, especially in the urban and rural markets. On a daily basis, animals are butchered and their meats are sold for public consumption [21]. There are various forms of abattoir wastes, they include animal faeces, paunch manure, abattoir effluent, bones, animal blood and horns. Abattoir wastes possess the potential to pollute underground and surface waters, markets and abattoir environment, and consumables around the abattoir especially when the wastes are not properly treated and disposed [22]. Unfortunately, animal wastes (bones) when not disposed properly are unsightly; they occupy useful space; are odorous and attract flies and can cause nuisance. In view of these challenges, an innovative and sustainable approach to reduce this looming environmental threat is to recycle these wastes [21]. In a research by [1], rice husk ash was used as partial replacement for filler in bituminous concrete mixture. His findings revealed improvements in the properties of modified samples in terms of Marshall stability, indirect tensile test, volumetric properties and water sensitivity. There was particularly an increment of 65% in Marshall stability over the conventional filler and control which was cement. According to [6], date seed ash (DSA), an agricultural waste by-product was used as partial replacement for filler in hot mix asphalt (HMA). The effect of the DSA filler on the mechanical properties of the asphaltic concrete was evaluated using indirect tensile stiffness modulus, Marshall stability, four-point bending fatigue and wheel track tests. According to the results, asphalt mixtures modified with DSA filler performed better in view of stiffness modulus and Marshall stability compared to the conventional or control mix. Besides, the use of biomass ashes had significant improvement on the thermal sensitivity of the modified mixes and the binding force between bitumen and aggregates, which enhanced the fatigue life and rutting resistance of the asphalt mixture [6]. In a recent research by [21], waste materials generated was estimated based on calculations. The result showed that on the average, about

50-55 cattle, 125-130 sheep and goats were slaughtered daily at the abattoir in Jalingo metropolis. According to a research by [23], waste cow bones have been used over the years as modification for asphalt in a form called Bone Glue Modified Asphalt. They investigated the possibility of using collagen extracted from animal bones, hides and flesh waste as protein-based glue (Bone Glue) to create asphalt with a modified asphalt binder. The result showed that a 10% Bone Glue modified binder exhibited significant improvements at all frequencies and especially at lower frequencies or higher temperatures. It also demonstrated that a 10% Bone Glue content was the optimal content for asphalt modification and that the fatigue life increased with an increase in Bone Glue content. Fapohunda *et al.*, (2014) [24] also investigated the use of machine crushed cow bone (MCCB) in light weight concrete and from their findings they discovered that it was easy to produce light weight concrete using MCCB as fine aggregate by partially replacing normal fine aggregate with MCCB up to a maximum of 50% with values comparable with the conventional mix. The workability of the concrete was observed to have reduced, using MCCB (fine aggregate). Interestingly, Artificial Neural Network (ANN) is a computational and an organized network technique used to understand complex systems. It possesses the ability to learn from examples through iteration, without requiring a prior knowledge of relationships between variables under investigation [25]. Furthermore, in civil engineering applications and predictions, ANNs have been extensively used to forecast complex variables in various subject areas. In the area of pavements, it is also widely used efficiently to predict difficult data that cannot be generated without lengthy experiments or sophisticated models [26]. In view of the aforementioned literature, there has been little or no research efforts on the potentials of degradable wastes as fillers in asphaltic concrete especially CBA. It is therefore the intention of this study to examine the possibility of utilizing CBA with a view to modifying the engineering properties of binder and filler when used as partial replacement in hot mix asphalt. While more consumption of the cow bones assures better and cleaner environment, the reduction in the use of our natural materials can in turn reduce the cost of pavement works [27].

## 2. Materials and Methods

### 2.1 Materials

#### Mineral Aggregates

The conventional mineral aggregates utilized for this research were sourced from Landmark University construction site. The coarse aggregates comprised particles sizes larger than 2.36mm while the fine aggregates consist of particle sizes less than 2.36mm) The coarse aggregates used were crushed granite chippings while the fine aggregates were river bed sand. They were washed and dried bore subjecting them to the required tests.

#### Bitumen

PG 60/70 of bitumen was used in this research to produce both control and modified samples of Hot Mix Asphalt (HMA). It was gotten from the Geotechnics and Highway Engineering Laboratory of Landmark University Omu-Aran, Nigeria.

#### Fillers

The conventional mineral filler used was gotten from sieve analysis of quarry dust which is the particle passing through sieve no 200 and retained on the pan; while waste cow-bone was sourced from Odo-Eran abattoir in Omu-Aran, Nigeria. They were sorted, dusted, washed (to remove traces of fat present) and milled to powder as shown in Figure 1a, to obtain a large surface area and thereafter sieved using US sieve No. 200 or 75 $\mu$ m, and finally ashed as shown in Figure 1b to prevent bacterial attack. The conventional filler was used to produce control samples while the cow-bone ash was used to produce modified samples.



Figure 1. (a) Milled Cow bone, (b) Cow bone Ash

## 2.2 Method

### 2.2.1 Material Testing

The test on materials was done to determine the suitability of the materials for this research and especially their suitability to produce the control asphaltic concrete and the modified specimen.

### 2.2.2 Tests on Mineral Aggregates

The tests carried out on the coarse and fine aggregates used were namely flakiness index test, aggregate impact test, elongation test, specific gravity, voids percentage, water absorption test, Los Angeles Abrasion test, bulk density test and moisture content tests.

### 2.2.3 Water/Moisture Content Test

Moisture containers were labelled and properly weighed. Samples of wet soil were poured into the containers and weighed after which they were placed in the oven at  $105^{\circ}\text{C} \pm 5^{\circ}\text{C}$  for about 20 to 24 hours. The moisture content was computed as follows:

$$\text{Water Content} = \frac{(W_2 - W_3)}{(W_3 - W_1)} \times 100 \dots \dots \dots (1)$$

Where;  $W_1$  = weight of can

$W_2$  = weight of wet soil + can.

$W_3$  = weight of dry soil + can

## 2.3 Tests on Bitumen

### Ductility test

The ductility test on bitumen according to (ASTM D113)[28] was to determine the distance a standard asphalt sample will stretch without breaking under standard testing condition (5 cm/min at  $25^{\circ}\text{C}$ ). It was also to determine whether the asphalt has good or poor adhesive properties and therefore help predict performance in service.

### Flash and Fire Point Test;

To determine the temperature to which the control and modified samples can be safely heated in the presence of an open flame, the flash and fire point test was conducted. The test was performed using the Pensky-Martens Closed Tester method (ASTM D93) [29] which tends to give more indicative results. Other tests

carried out on bitumen are: Softening Point test, Solubility test, loss on heating test; float test, Penetration test, Viscosity test, Specific gravity test, Spot test, and Water content test according to the specifications listed in [30].

#### 2.4 Blending of aggregates

To achieve an aggregate blend that meets gradation specifications for an asphalt mix, the sourced aggregate materials, coarse and sand were integrated to determine the particle size distribution with the aid of mathematical trial method and within the specified. The proportions of each of the aggregate sizes were calculated and compared to specification limits. The trials were repeated until the percentage of the sizes of the aggregates were within allowable limits[31].

#### 2.5 Marshall test

To achieve the desired properties of durability and strength, the bitumen content at optimum to be added to mineral aggregates was calculated using the Marshall method for designing hot mix asphalt. According to standard 75-blows Marshall design method which is designated as (ASTM D 1559-89)[32], 10 samples each of 1200 gm. in weight were prepared using five different bitumen contents (from 4.5 – 6.5% with 0.5% increment). Two asphalt mixtures were prepared, with the bitumen content of one of the samples to have an average value of marshall stability, bulk density and flow. For each of the modified samples and the control, the bitumen content was determined for the various Marshall Properties of the asphalt mix such as stability, flow, density, air voids in total mix, and voids filled with bitumen. To obtain optimum bitumen content, the following graphs of Bulk Specific Gravity vs. bitumen Content, Flow vs. Bitumen Content, and Stability vs. Bitumen Content were plotted.

#### 2.6 Determination of Optimum Bitumen Content (OBC)

OBC for the proposed mixes was obtained from the average of three values of bitumen content[33], which include: a) bitumen content at the highest stability (%) Stability, b) bitumen content at the highest value of bulk density (% mb) bulk density and c) bitumen content at the median of allowed percentages of air voids ( $V_a = 3 - 5\%$ )(% mb) $V_a$ . Marshal graphs were utilized to obtain these three values.

$$\text{Optimum Bitumen Content} = \frac{(\%)Stability + (\%)Bulk\ Density + (\%)Vvoids}{3}$$

The asphalt mix properties using optimum bitumen content such as stability, flow,  $V_v$ , bulk density and VMA were obtained and compared with the standard design specifications ranges for medium trafficked roads as shown in Table 1.

**Table 1. Standard Design Specifications for Medium Traffic Roads**

Criteria	Mixture type		Requirements
Air voids (%)	dense-graded course	wearing	3 - 5
Voids filled with bitumen VFB (%)	dense-graded course	wearing	75 - 85
Stability (KN)	dense-graded course	wearing	Not less than 7.5
Flow (mm)	dense-graded course	wearing	2 - 3
Optimum bitumen content (%)	dense-graded course	wearing	5.0 – 8.0

**Source:** [34]

### 2.7 Preparation of Asphalt Mix Modified with Cow Bone Ash (CBA)

Sequel to obtaining the Optimum Bitumen Content (OBC), 10 samples were prepared at the OBC to evaluate the effect of adding CBA to asphalt mixture samples by considering eight proportions of the CBA (2.5%, 5%, 7.5%, 10%, 20%, 30%, 40% and 50 %) by the weight of OBC. The procedure employed to incorporate CBA in the asphalt mix is summarized as follows; Cow bone was washed, milled, ashed and sieved to have a size 0.075mm; Requisite amount of CBA was mixed with the conventional filler (quarry dust) and heated to about 150-170°C; The fine and coarse aggregates were heated at the same temperature for the same period but in separated pan; Requisite amount of bitumen was heated to about 150-165°C; CBA and quarry dust mixture were thereafter mixed with fine and coarse aggregates and followed by addition of hot bitumen at OBC. A homogeneous asphalt mix was achieved at 165°C through the vigorous mixing of all ingredients. After preparing modified asphalt mix, specimens were prepared, compacted as shown in Figure 2 and tested according to standard 75-blows Marshal Method designated as (ASTM D1559-89). [30]



**Figure 2. Samples of compacted modified specimen**

### 2.8 ANN Analysis and Model

ANNs in recent years have been employed to model the properties and behavior of materials, and to analyze the complex relationships between their vastly different properties in many civil engineering applications, because of their ability to learn and to adapt[35]. For the ANN analysis, the quick propagation (QP) algorithm was utilized among other algorithms such as the Incremental Back Propagation (IBP), Batch Back Propagation (BBP), Levenberg Marquardt (quasi Newton) and genetic algorithm (GA)[36]. During the training of experimental data QP gave the least root mean square error RMSE at the shortest time. The network consists of the input layer, hidden layer and the output layer. The number of neurons in the input and output layers is usually determined by the number of inputs and outputs investigated in the study. For this study the input neurons were % CBA, Weight in air and Weight in water while the output neurons were Density, Volume of bitumen, Stability, Flow, Volume of Voids (Vv), Voids in mixed aggregates (VMA), Voids filled with bitumen (VFB) and Optimum bitumen content (OBC). A single hidden layer was utilized in this study as recommended by Hush and Horne (1993)[37] while the number of neurons in the hidden layer was determined through the process of try and error. The training started with 5 neurons in the hidden layer and discovered that an increase in the number of hidden layers did not improve the performance of the network.

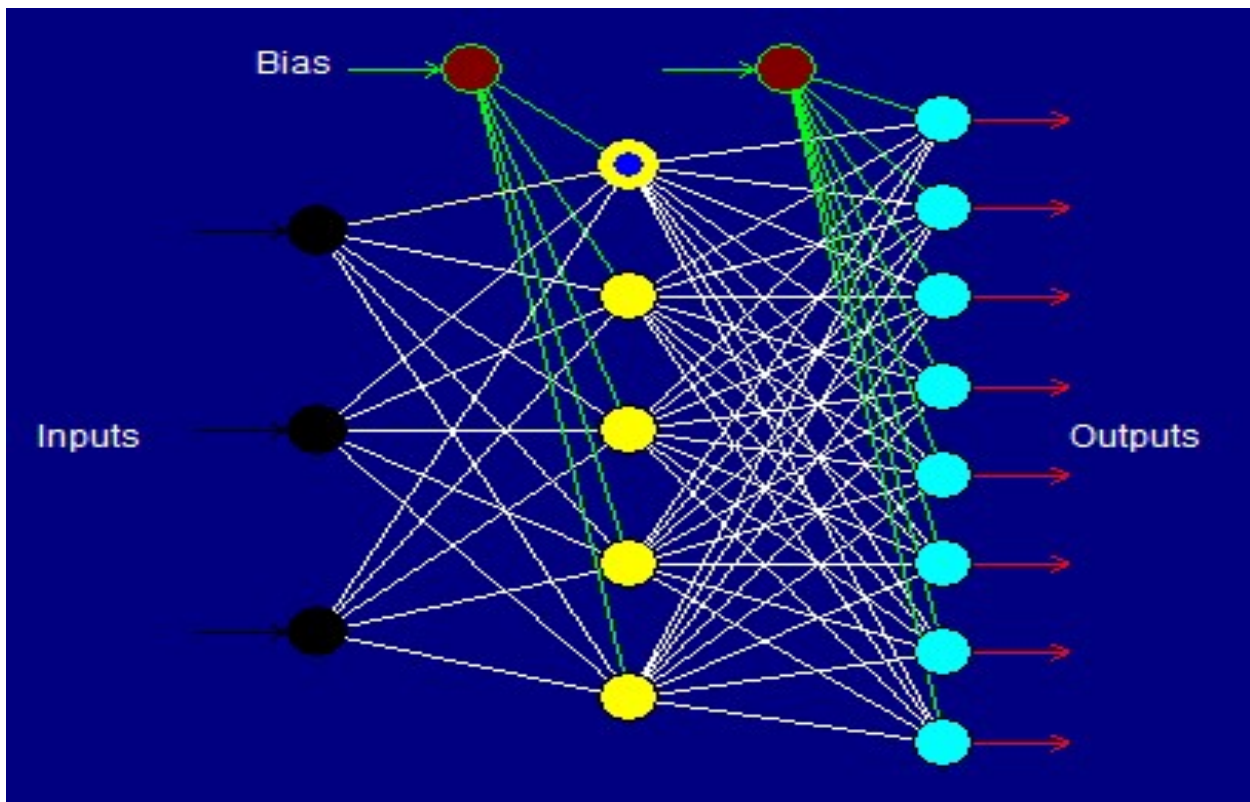
Figure 3 presents feed forward neural network designated as 3:5:8 which signifies three input neurons, five hidden neurons and eight output neurons. The neurons are connected to one another by adjustable weights as presented in figure 4. Another important parameter required for training the network is the transfer function. Among the several transfer functions available, the hyperbolic tangent (Tanh) was the most



suitable for both the hidden and output layers. This transfer function computes its output to the subsequent layer using equation 2. In equation 2,  $\varepsilon(\mu_k)$  denotes the transfer function and Alpha ( $\alpha$ ) is called slope of transfer function using the CPC-X software (2003).

$$\varepsilon(\mu_k) = \frac{1 - \exp(-\alpha\mu_k)}{1 + \exp(-\alpha\mu_k)} \quad \text{-----} \quad (2)$$

The CPC-X software (2003) splits the data into two sets which are the training and the testing sets. The following experimental data 2, 3, 5, 6, 8 and 9 and their corresponding outputs were used for training, while



**Figure 3. The ANN model architecture**

1, 4 and 7 were used as testing as presented in Table 2. The number of iterations and time elapsed at the end of training were 17,223 and 6s respectively. The generalization capacity of the test data set was determined by the RMSE, mean prediction error (MPE) and the absolute fraction of variance (AFV).





Figure 4. The weight distribution for the ANN model

Table 2. Experimental data used for the ANN model

Test no.	% MCB	Weight in air (g)	Weight in water (g)	Density g/cm <sup>3</sup>	Vol of bitumen (vb)	Stability (kN)	Flow (mm)	Vv (%)	VMA	VFB (%)	OBC
1	<b>0</b>	<b>1338.2</b>	<b>745.8</b>	<b>2.38</b>	<b>10.638</b>	<b>36</b>	<b>11.3</b>	<b>9.99</b>	<b>20.63</b>	<b>80</b>	<b>4.63</b>
2	2.5	1147.5	659.8	2.24	13.99	40.9	12	4.37	18.32	94.04	5.58
3	5	1105.1	615.8	2.16	13.48	36.7	12.5	8.06	21.52	80.24	5.34
4	<b>7.5</b>	<b>1105.1</b>	<b>615.8</b>	<b>2.16</b>	<b>13.46</b>	<b>30.6</b>	<b>12.5</b>	<b>7.99</b>	<b>21.45</b>	<b>80.53</b>	<b>5.78</b>
5	10	1123.3	618.4	2.3	13.28	46	13	9.24	22.52	84.99	6.23
6	20	1171	654	2.35	13.53	66.3	13	7.36	20.89	90.22	5.95
7	<b>30</b>	<b>1262.7</b>	<b>709.6</b>	<b>2.32</b>	<b>13.58</b>	<b>56.6</b>	<b>13</b>	<b>6.52</b>	<b>20.09</b>	<b>89.97</b>	<b>6.08</b>
8	40	1385.1	785	2.48	13.66	55	13	5.15	18.81	78.01	5.33
9	50	1376.2	783.2	2.43	13.77	57.1	10	3.98	17.75	91.47	5.2

*Bold characters represent the test data set of the constructed ANN models*

### 3. Results and Discussion

Laboratory test results on control sample, including the partially replaced samples are presented as follows: The test results on aggregates and bitumen include grain size analysis, ductility test, penetration test,

softening point test, aggregate impact test, etc., and marshal stability test. The study was conducted through standardized laboratory test methods following set standards and specifications at the highway laboratory of Landmark University, Omu Aran, Nigeria.

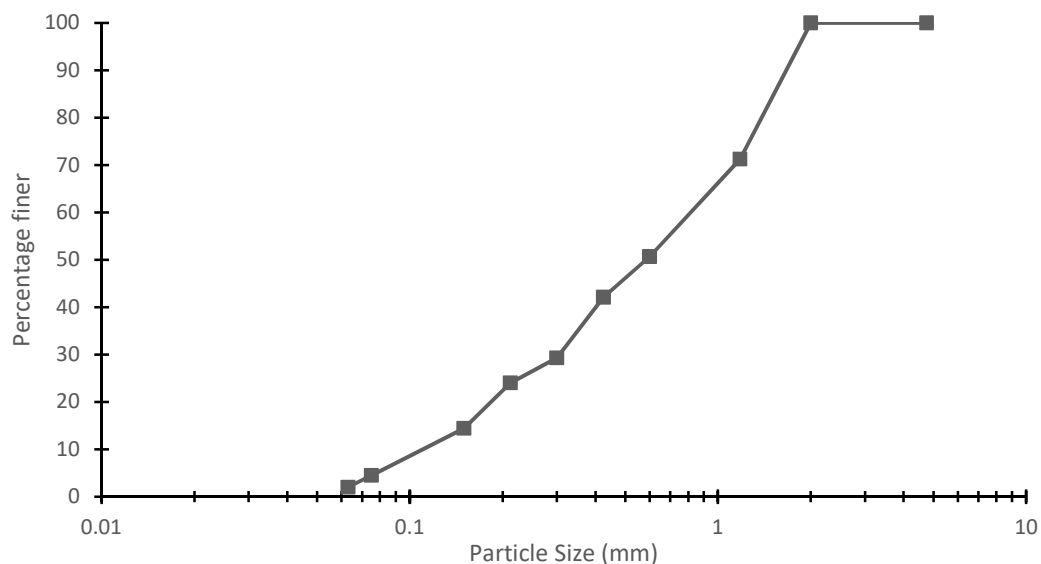
### 3.1 Particle size Distribution Results

The particle size distribution table for the fine aggregates used in the preparation of the asphalt is as shown in Table 3. The percentage passing the sieves show a well graded distribution of aggregates for the control mix.

**Table 3. Sieve analysis for fine aggregate**

Sieve No	Diameter(mm)	Wt. of empty sieve(g)	Wt of sieve + retained soil(g)	Wt of soil retained(g)	Percent retained (%)	Percent passing (%)
1	2	538	541	0.5	0.05	99.95
2	1.18	491.5	492	0.5	0.05	99.9
3	0.6	476.5	499.5	23	2.3	97.6
4	0.425	437.5	863.5	426	42.6	55
5	0.3	449	853	404	40.4	14.6
6	0.212	408	494	86	8.6	6
7	0.15	400.5	424	23.5	2.35	3.65
8	0.075	368	384	16	1.6	2.05
9	0.063	381.5	390.5	9.5	0.95	1.1
	pan	399	399	1.1	1.1	0
			total	999.9	100	

Figure 5 shows the particle size distribution curve for the coarse aggregates used in the preparation of the base asphalt. It shows a well-graded distribution of the aggregates according to requirements for a dense-graded mix.



**Figure 5. Particle Size Distribution Curve for Coarse Aggregates**

Table 4 shows the results of the various tests conducted on the coarse aggregate, the values gotten showed that the aggregates met the basic requirements according to standard thereby making it suitable for the construction of flexible pavement.

**Table 4. Physical Test Results on Coarse Aggregates**

Test Carried Out	Obtained Test Results	Standard Test Values
Aggregate Impact Test	24.98%	30% Maximum
Aggregate Crushing Test	44.93%	45% Maximum
Los Angeles Abrasion Test	56.03	60% Maximum
Flakiness Index	28.62	30% Maximum
Elongation Index	29.53	30% Maximum
Density	1492.267kg/m <sup>3</sup>	
Specific Gravity	2.8	2.8

### 3.2 Tests on Bitumen

The results of the tests on bitumen are presented in Table 5. It summarized the outcome of the basic engineering properties of bitumen and hence established its suitability for use in the preparation of the control and modified samples of asphaltic concrete.

**Table 5. Tests of bitumen**

PARAMETERS TESTED	A	B	C	AVERAGE
Penetration (mm)	82	89	78	83
Softening Point (°C)	60	54	58	57.3
Ductility (cm)	91	86	90	89
Viscosity (secs)	68	77	81	75.3
Flash point (°C)	275	270	278	274.3
Fire point (°C)	298	305	308	303.7
Specific gravity	0.96	0.96	0.98	0.97
Loss on heating (%)	0.88	0.84	0.87	0.86
Moisture content (%)	0.0021	0.0024	0.0022	0.0022

### 3.3 MARSHALL PROPERTIES TEST RESULTS

Presented in Table 6 are the Marshall properties test results of the control and modified samples of asphaltic concrete.

#### 3.3.1 Control

**Table 6. Marshall Stability Test Results for the Control Samples**

Sample no	% bc	Mass in air	Mass in H <sub>2</sub> O	Gt	Gm	Volume of voids (Vv)	% volume of bitumen (Vb)	VMA (%)	VFB
1	5.5	1256.5	728.5	2.472	2.38	3.722	13.635	17.357	78.556
2	5	1353.5	755	2.493	2.261	9.306	11.776	21.082	55.858
3	4.5	1350.5	738.5	2.514	2.207	12.212	10.345	22.557	45.862
4	4	1385	762.5	2.536	2.225	12.263	9.271	21.534	43.053
5	3.5	1345.5	744.5	2.558	2.239	12.471	8.163	20.634	39.561

The corrected Marshall stability in relation to other volumetric properties of the control sample are as presented in Table 7.

**Table 7. Marshall Stability Corrections**

Sample No	Uncorrected Stability (KN)	Cf	Corrected stability (KN)	Flow (mm)	% Bitumen Content	Wt of CA	Wt of FA	Wt of Filler	Wt of Bitumen
1	32.6	1	32.6	6.5	5.5	2700	240	840	220
2	26.1	1	26.1	10	5	2720	240	840	200
3	31.6	1	31.6	10.5	4.5	2740	240	840	180
4	36	1	36	9	4	2760	240	840	160
5	27	1	27	11	3.5	2780	240	840	140

In Table 8, the optimum bitumen content was obtained from the average of corresponding bitumen contents for the stability, maximum bulk specific gravity of the mix, flow and the volume of voids of the control sample. Therefore, the Marshall mix design for the control sample will be: **68.37: 6: 21: 4.63** which implies **CA (68.37%): FA (6%): Filler (21): Bitumen (4.63)**. The optimum bitumen content of the control sample was less than that of the CBA at 50% replacement. Also, the CBA filled more voids than the conventional filler, hence making it a good substitute for filler in asphaltic concrete.

**Table 8. Bitumen Content Values of Marshall Parameters**

PARAMETERS	BITUMEN CONTENT
Maximum Stability	4
Maximum Gm	5.5
Maximum Flow	3.5
$V_v = 4\%$	5.5
Average	4.625

**THE OPTIMUM BITUMEN CONTENT = 4.625%**

Table 9 shows that as the volume filled with bitumen (VFB) increases, so also does the bitumen content, that is the volume filled with bitumen is directly proportional to the bitumen content.

**Table 9. Summary of Marshall Test Results of the Control and Modified Samples**

% CBA	Weight in air (g)	Weight in water (g)	Density g/cm <sup>3</sup>	Vol of bitumen (vb)	Stability (kN)	Flow (mm)	Vv (%)	VMA	VFB (%)	OBC
0	1338.20	745.80	2.38	10.638	36.00	11.3	9.99	20.63	80.00	4.63
2.5	1147.50	659.80	2.24	13.99	40.90	12.00	4.37	18.32	94.04	5.58
5	1105.10	615.80	2.16	13.48	36.70	12.50	8.06	21.52	80.24	5.34
7.5	1105.10	615.80	2.16	13.46	30.60	12.50	7.99	21.45	80.53	5.78
10	1123.30	618.40	2.30	13.28	46.00	13.00	9.24	22.52	84.99	6.23
20	1171.00	654.00	2.35	13.53	66.30	13.00	7.36	20.89	90.22	5.95
30	1262.70	709.60	2.32	13.58	56.60	13.00	6.52	20.09	89.97	6.08
40	1385.10	785.00	2.48	13.66	55.00	13.00	5.15	18.81	78.01	5.33
50	1376.20	783.20	2.43	13.77	57.10	10.00	3.98	17.75	91.47	5.20

From the above Marshall test results of CBA modification at 2.5%, 5%, 7.5%, 10%, 20%, 30%, 40% and 50% respectively, all have a higher optimum bitumen content than that of the control specimen, this shows that the CBA is a good replacement for filler in asphaltic concrete. Also, from table 9, the stability, flow, volume of voids, voids filled with bitumen and the optimum bitumen content met the requirements of the standard design specifications for Medium trafficked roads (according to American Asphalt Institute)

### 3.4 Results and Discussion of the ANN model

RMSE, MPE and AFV as earlier described were utilized in the developed ANN model to statistically measure the performance of the test data and is presented in Table 10. The RMSE, MPE and AFV values obtained are 0.098, 0.033 and 0.998 respectively and accounting for density, 1.381, 0.245 and 0.987 respectively for volume of bitumen, 7.585, 2.133 and 0.987 respectively for stability, 1.047, 0.766 and 0.991 respectively for flow, 1.848, 1.181 and 0.929 respectively for Vv, 0.811, 0.588 and 0.998 respectively for VMA, 4.278, 1.525 and 0.997 respectively for VFB and 0.628, 0.066 and 0.986 respectively for OBC. The statistical values in table 10 show that the ANN model was able to successfully analyse and predict the experimental data.

**Table 10. Performance measurement of test data**

Statistical Performance Indicators	Density g/cm <sup>3</sup>	Vol. of bitumen (Vb)	Stability (KN)	Flow (mm)	Vv (%)	VMA	VFB (%)	OBC
RMSE	0.098	1.381	7.585	1.047	1.848	0.811	4.278	0.628
MPE	0.033	0.245	2.133	0.766	1.181	0.588	1.525	0.066
AFV	0.998	0.987	0.969	0.991	0.929	0.998	0.997	0.986

The influence of the input parameters on all outputs investigated are illustrated on the line charts shown in Figures 6 and 7. The line charts presented in Figure 6 was obtained by varying input factors % CBA and weight in air between 0-50 and 1105.1-1385.1 respectively with the third input factor (weight in water) held constant at 700g. It was observed from this figure that the outputs viz density, stability, flow, Vv, VMA and VFB tend to increase with increasing % CBA and weight in air, while the outputs viz volume of bitumen

and OBC tend to reduce % CBA and weight in air. Figure 7 presents the line charts of % CBA and weight in water varied between 0-50 and 615.8-785 respectively while weight in air was held constant at 1245.1g. The density increased with increased % CBA and weight in water. Outputs such as stability,  $V_v$ , volume of bitumen, VMA and OBC decreased with increased % CBA and weight in water. For VFB and flow, optimum values of 700 and 650 respectively were observed for weight in water with reduced % CBA.

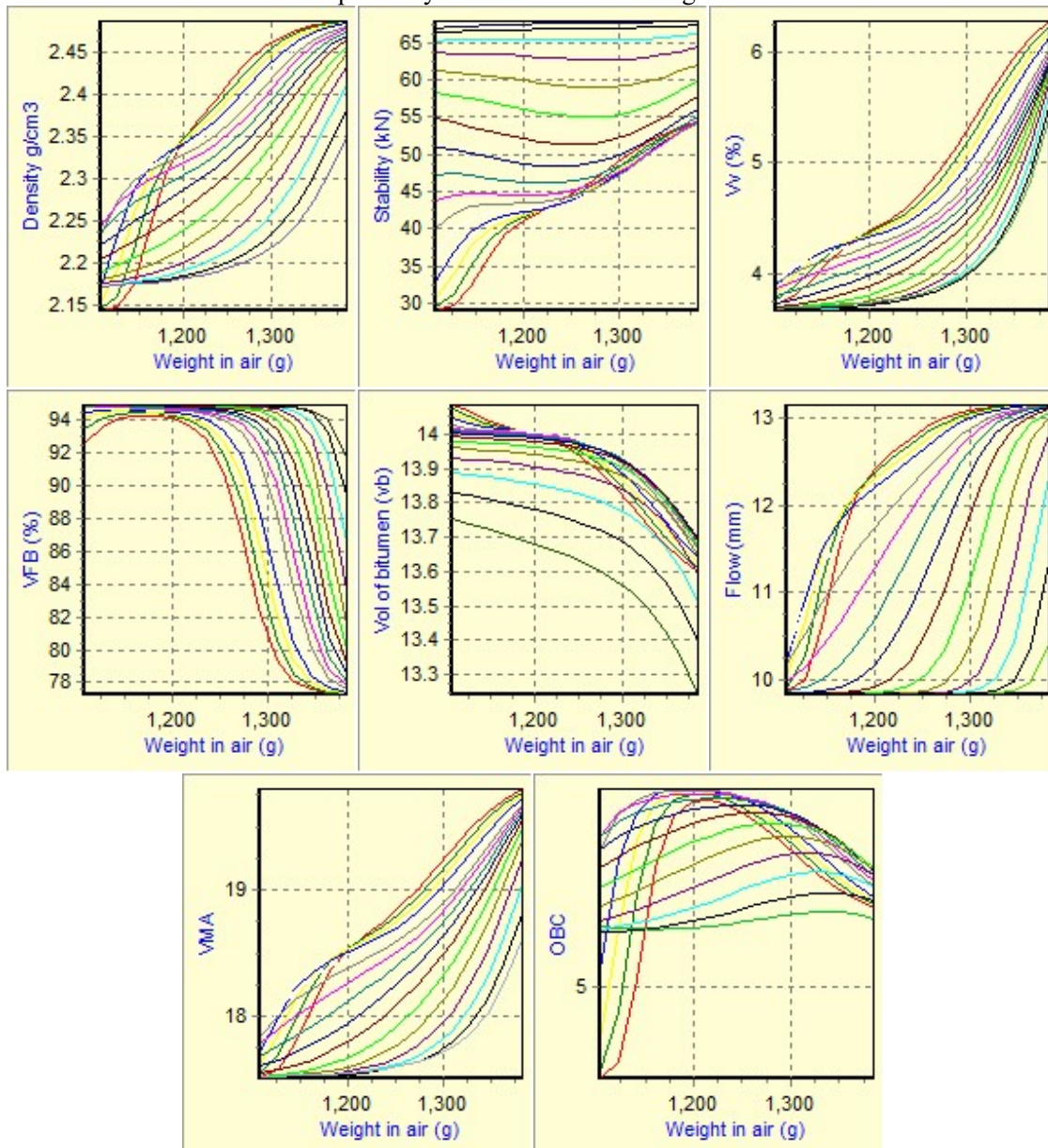
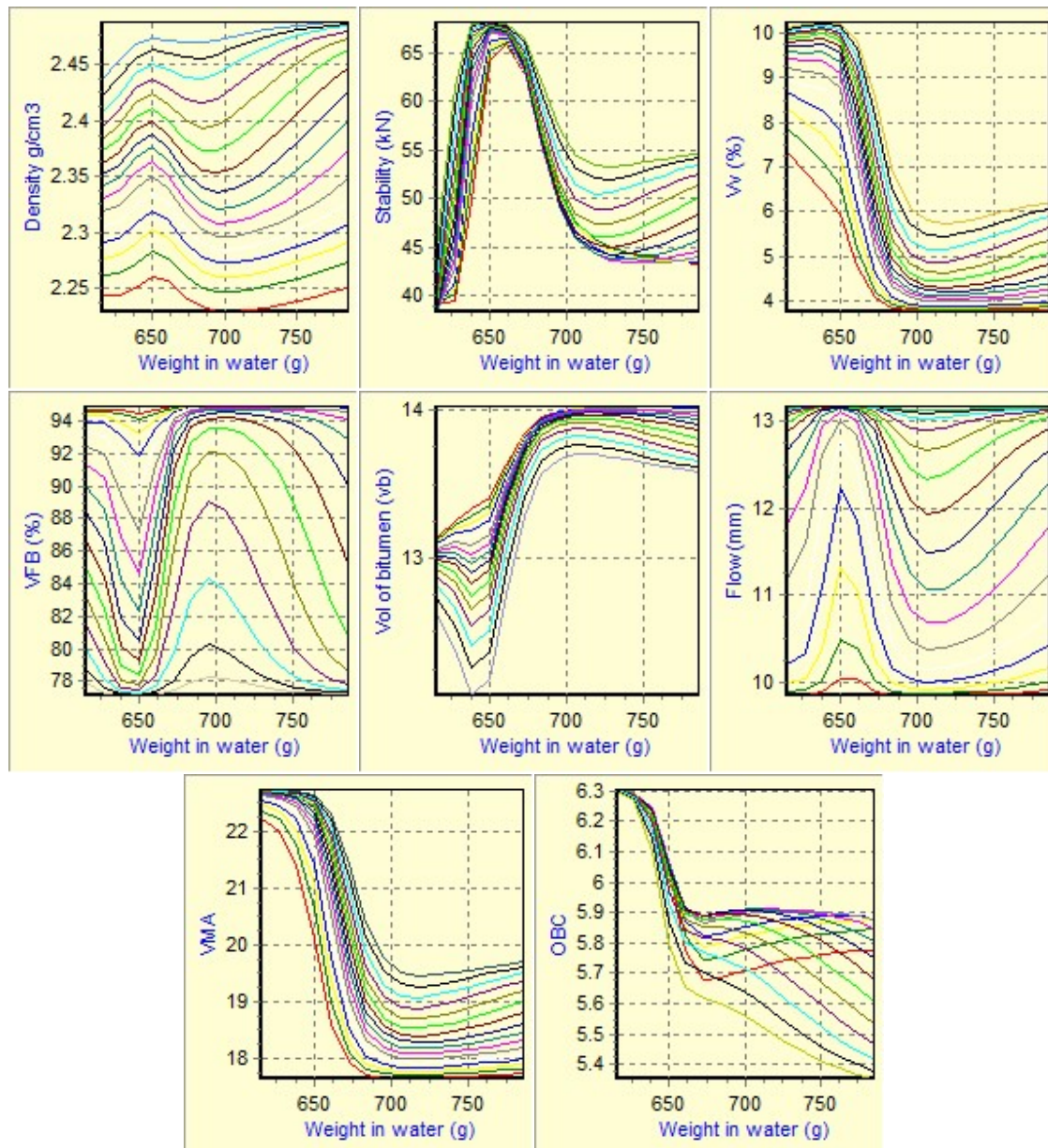


Figure 6. Line chart showing the relationship between % CBA and weight in air

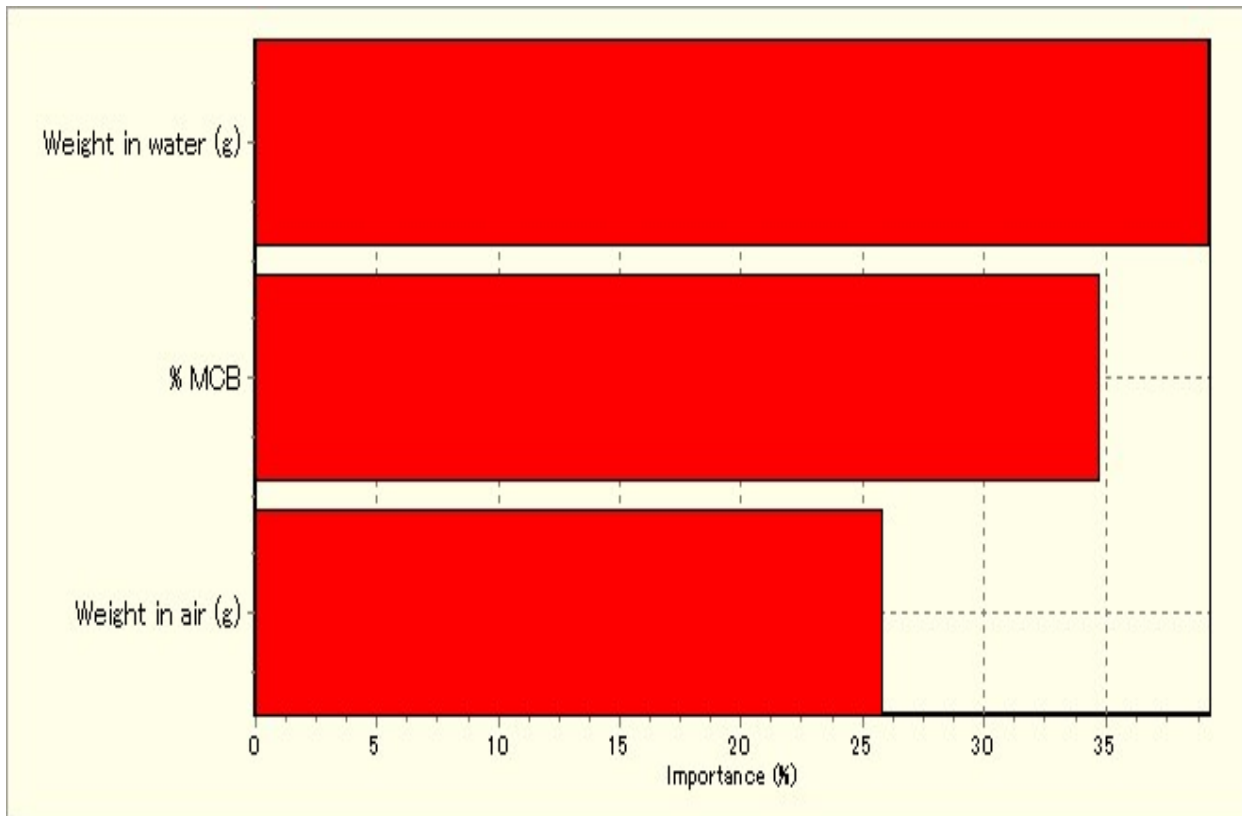




**Figure 7. Line chart showing the relationship between % CBA and weight in water**

In addition, the relative importance of the input factors in the predicting process is presented in Figure 8. From this Figure it can be inferred that weight in water contributed the most followed by the % CBA and lastly weight in air. Furthermore, the input factors were optimized using the optimal algorithm search approach as presented in Table 11. Genetic algorithm (GA), a popular form of the optimal algorithm was used for this purpose. The genetic algorithm comprises a cross over rate of 0.8, population size of thirty (30), absolute top mate selection type, mutation rate of 0.1, and uniform crossover type. It was observed from the optimization process that for maximum outputs of density, stability, flow, volume of bitumen, Vv,

VMA, VFB and OBC, the quantities each of the input factors (% CBA, weight in air and weight in water) should be 33.06467, 1231.265 and 656.9546.



**Figure 8. Importance of effective parameters in the production of Cow-bone Modified Asphalt**

**Table 11. Optimization process by optimal algorithm**

Parameter	Output
Density g/cm <sup>3</sup>	2.311408
Vol of bitumen (vb)	13.02156
Stability (kN)	67.22837
Flow (mm)	11.7426
V <sub>v</sub> (%)	8.155808
VMA	21.59439
VFB (%)	91.65166
OBC	6.060355
<b>Parameter</b>	<b>Input</b>
% CBA	33.06467
Weight in air (g)	1231.265
Weight in water (g)	656.9546

#### 4. CONCLUSION

In this research, the performance of asphaltic concrete modified with cow-bone ash has been evaluated using the Marshall mix design method and artificial neural networks. The analysis was done by partially replacing conventional filler with the cow-bone ash and determining its effect on the Marshall stability and flow of the resultant blends. This has shown that it is possible to produce bituminous concrete with sustainable agricultural wastes and still obtain improved desirable properties as shown in the results. From the results obtained, a 2.5% to 50% replacement of the conventional filler with CBA with particle size of 0.075mm is suitable for the construction of medium trafficked highway pavement surfaces. It was also noted that the Marshall stability obtained was higher than the standard which makes it suitable for use and a good replacement for filler in asphaltic concrete. Furthermore, from the ANN analysis, the input parameters with the most significant contribution to the Marshall and volumetric properties of the cow-bone ash modified asphalt were weight in water, followed by the % CBA and lastly, weight in air. The statistical values obtained showed that the ANN model was able to efficiently learn and predict the experimental data.

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