ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE June 2023. Vol. 19(2):367-380
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

PERFORMANCE EVALUATION OF HOT MIX ASPHALT USING COW DUNG ASH AS FILLER

A. A. Murana, V. Ude and A. Suleiman*

Department of Civil Engineering, Ahmadu Bello University, Zaria, Kaduna State, Nigeria
**Corresponding author's email address: abdulsuleiman@abu.edu.ng*

ARTICLE INFORMATION

Submitted 22 August, 2022
Revised 11 February, 2023
Accepted 15 February, 2023

Keywords:
Performance evaluation
Hot mix asphalt
Cow dung ash
Filler material

ABSTRACT

This study evaluates the performance of Cow Dung Ash (CDA) in hot-mix asphalt. This was achieved by determining the Marshall and volumetric properties of Hot Mix Asphalt (HMA). In the HMA, cow dung ash partially replaced granite dust at varying percentages using varying bitumen content. The results obtained from the laboratory experiments indicate an increase in stability with an increase in CDA and bitumen content. Maximum stability of 11.8 kN was obtained at 40% CDA and 6% bitumen content. The flow was observed to increase with increasing CDA and bitumen content. A minimum flow of 2.7 mm was observed at 5% bitumen and 10% CDA content. The unit weight increases with an increase in bitumen and CDA content while an increase in CDA considerably decreases the void in the mineral aggregate of the mix. Additionally, the increase in bitumen and CDA content showed a decrease in air voids of modified mix. Results obtained showed that an increase in the percentage of void filled with bitumen is directly proportional to bitumen and CDA content. The Marshal properties such as stability and flow and the volumetric properties such as unit weight, Void in Mineral Aggregate (VMA), air voids and voids filled with bitumen were within the range specified by Nigerian General Specification for Road and Bridges. It can be concluded that the Marshall and volumetric properties of hot mix asphalt performed well with CDA as filler and hence, can be recommended for use in hot mix asphalt.

1.0 Introduction

The development of any nation could be linked to an effective and well-planned transport network and other infrastructures. Conversely, inadequate transport networks inhibit the level of development a nation can attain. Road transport is the most common means of transportation in many nations including Nigeria. However, the poor state of roads in Nigeria has hindered development and has affected many aspects of life Poor road condition, either as a result of poor construction or maintenance practices has necessitated the search for solutions to improve the condition of pavement (Nwafor and Onya, 2019). In recent times, efforts have been channelled towards utilizing waste materials in the construction industry, especially using organic waste (Yaro et al., 2022; Badejo et al., 2017; Shuaibu et al., 2019; Milad et al., 2020; Abdulfatai et al., 2023). Olusegun and Sam (2012) referred to these waste materials as biomass, since they are derived from carbonaceous waste due to natural and human activities The use of cement in asphalt concrete (Anand et al., 2006) has led to increased cement demand and production. The increase in cement production causes an increase in CO_2 (greenhouse gas) and other poisonous gas emissions from production plants and haulage trucks which transport raw materials to factories, and finished products to market. This scenario is against the world campaign to reduce the depletion of the ozone layer since it leads to global warming. These challenges prompted the need to seek alternative cementitious materials which can completely or partially replace cement. A potential material which could partially replace cement is cow dung.

Cow dung is the excreta of herbivorous bovine animals popularly known as cattle. It usually comprises of faeces and urine in a ratio of 3:1 and contains minerals like magnesium, potassium, manganese, and some other minor minerals (Gupta et al., 2016). Cow dung has a significant amount of ash content, which is bulky, has low carbon content and reduced volatile content after burning. Cow dung is used to generate biogas for electricity and generate heat in mud brick houses (Rayaprolu and Raju, 2012). According to (Gupta et al., 2016), cow dung is used in Indian villages for plastering walls, cooking through burning generates heat, and the ash as a cleaning agents. Salisu (2007) reported that in 2001, Nigeria had an estimated 15.6 million cattle with a growth rate of 4.2% and 5.0% in 2002 and 2003 respectively. With an average of 10 kg to 15 kg of cow dung produced daily by a well-fed mature cow, there is bound to be enough cow dung produced on daily basis to be recycled (Olusegun and Sam, 2012). However, there is a need for proper management and disposal of animal waste to prevent environmental pollution and health challenges such as odour, airborne ammonia, greenhouse gases, and pathogen contamination shown by Abubakar and Ismail (2012) as cited by Saleh and Jibrin (2020).

There have been successes recorded by researchers like Zareei et al. (2017) in partially replacing cement with rice husk ash in concrete since it contains micro silica and Murana and Sani (2015) replacing cement with bagasse ash in hot mix asphalt. Here, we focused on partially replacing quarry dust with cow dung ash as filler in hot mix asphalt. Hot mix asphalt is a dense combination of bitumen, coarse aggregate, fine aggregate and mineral filler which relies on the interlocking properties between the aggregate particles for strength and to a lesser extent, the properties of bitumen and filler. Hearn et al. (2015) affirmed that asphalt should be used to describe all bituminous mixes used in pavement construction. For filler, which are materials finer than 0.075 mm, Portland cement, hydrated lime and fines of crushed rocks are used. To improve the adhesion of bitumen and aggregates, cement of 1 - 2% by weight of the total mix is added to the natural filler. The void content and stiffness of the ratio of bitumen-fines are affected by the filler (TRL, 2002). Ojedokun et al. (2014) investigated partially replacement of cement with CDA in cement concrete. In the research, it was replaced at 0%, 10%, 20% and 30%. The workability and consistency test conducted on the concrete and cement paste was found to increase with increased CDA content. Furthermore, prolonged curing increased the strength with 10% CDA replacement producing 98% strength when compared with the control at 0%. Thakur et al. (2019) investigated the effect of CDA on the physical properties of concrete. In the work, the cement was partially replaced with 5%, 10% and 15% CDA. From their finding, a 5% replacement level was recommended as optimum CDA content.

Large volumes of cow dung produced from feed yards are constantly on the rise year in year out, which is most often disposed of without treatment Abubakar and Ismail (2012). Human contact with these by-products of cattle could lead to the transmission of diseases such as tuberculosis, E-coli and Q fever whose clinical picture is similar to that of influenza (Essar et al. 2021). To reduce the negative effect of cow dung, this work evaluates the performance of Cow Dung Ash as a filler material in Hot Mix Asphalt production. ,

2. Materials and Methods

2.1 Materials

The materials used for this research include aggregates, filler (quarry dust), bitumen and Cow Dung Ash. The aggregates and quarry dust were sourced from Zaria quarry yard in Kaduna state, Nigeria. The bitumen used was the 60/70 penetration grade obtained from Mother Cat Construction Company located in Zaria. The cow dung was obtained from National Animal Production Research Institute (NAPRI), Zaria which was calcined at 500°C temperature.

2.2 Methods

The physical properties of cow dung and constituent materials (aggregates and bitumen) of Hot Mix Asphalt are determined. Also, Hot Mix Asphalt with blend of quarry dust/CDA as mineral filler are prepared, and Marshall and volumetric properties of HMA prepared with blend of quarry dust/CDA as mineral filler is prepared.

2.2.1 Marshal Stability Test

Marshal stability test was carried out on the Hot Mix Asphalt (HMA) sample containing granite dust as filler. The bitumen content was varied at 4.5%, 5%, 5.5%, 6% and 6.5% by weight of the total weight of the sample (1200g). The marshal test was conducted in accordance with ASTM D6926-16 (2016). The samples were first compacted at 75 blows on each side at a temperature of about 150°C. The results of the stability, flow and volumetric properties were evaluated to be satisfactory as accepted by Nigerian General Specifications for Roads and Bridges (FMWH 2016).

2.2.2 Volumetric Properties of the HMA

The volumetric properties conducted include stability, flow, void in mineral aggregate (VMA), void filled with aggregates (VFA), void in total mix and voids filled with bitumen

3. Results and Discussion

3.1 Preliminary Test on Bitumen

Table 1 shows the results of the preliminary test conducted on bitumen. The test show that the bitumen is a 60/70 penetration grade.

Table 1: Test Conducted on Unmodified Bitumen

S/N	Test Conducted	Unit	Result	Light Traffic	Medium Traffic	Heavy Traffic	Standard
1	Penetration	0.1mm	68	40/50	60/70	80/100	ASTM D5-20
2	Softening point	°C	53	52-60	48-56	42-50	ASTM D36-14
3	Ductility @ 25°C	cm	108	100 (Min)	100 min	100 min	ASTM D113-17
4	Specific gravity	NIL	1.02	1.01-1.06	1.01-1.06	1.01-1.06	ASTM D70-18a.
5	Flash-point	°C	269	250 (Min)	232 min	250 min	ASTM D92-18
6	Fire-point	°C	288	NIL	NIL	NIL	ASTM D92-18
7	Solubility in C_2S	%	100	99.5 min	99 min	99.5 min	ASTM D2042-15

3.2 Physical Properties of the Aggregates

Table 2 depicts the results of the test to determine the physical properties of the aggregates used for this research. From the results obtained, based on standard specification, the aggregates fall within the specified standard.

Table 2: Physical Properties of Aggregate

Properties	Test Value	Standard Spec.		Remarks	Standard
		Min.	Max		
Specific Gravity (Coarse)	2.63	2.6	2.9	OK	ASTM C127-15
Specific Gravity (fine)	2.54			OK	ASTM C127-15
Specific gravity (Granite dust)	2.63			OK	ASTM C127-15
Flakiness Index	31	-	35	OK	BS 812-105.2 (1990)
Elongation Index	23.8	-	25	OK	BS 812-105.2 (1990)
Aggregate Crushing Value (%)	20.52	-	30	OK	BS 812: Part 110 (1990)
Aggregate Impact Value	11.4	-	35	OK	BS 812: Part 112 (1990)

3.3 Sieve Analysis and Aggregate Gradation

Sieve analysis was conducted on the coarse aggregate, fine aggregate and filler material in accordance with (ASTM C136 /C136M-19 2006) to determine the particle size distribution of the aggregate used for this research. The result of the particle size distribution and gradation is represented in Figure 1. The gradation limits were found to be within the standards specified by (FMWH 2016). Therefore, the material is suitable for the design of hot mix asphalt.

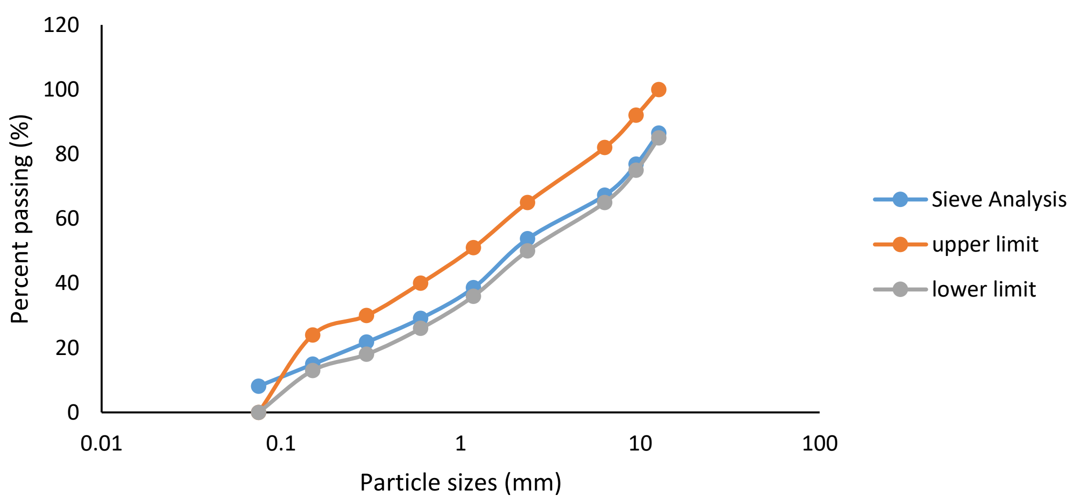

Figure 1: Aggregate Gradation Curve

3.4 Chemical Properties of Cow Dung Ash (CDA)

The oxide composition test was carried out in accordance with (ASTM D5381-93 2021) using X-Ray Fluorescence (XRF) technique. This test was carried out in Chemical Engineering Laboratory ABU Zaria. The concentration by weight of oxides is presented in Table 3.

Table 3: Chemical Composition of Cow Dung Ash

Element	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	Fe_2O_3	TiO_2	Mn_2O_3	SrO
Conc.(%)	2.36	5.37	46.649	1.61	1.22	5.41	3.102	6.210	2.97	2.066	0.573	1.052

A sample of the CDA and that of SiO_2, Al_2O_3 and Fe_2O_3 were analysed. The concentrations of the SiO_2, Al_2O_3 and Fe_2O_3 were found to be 46.64, 5.37 and 2.97 respectively. The summation of the concentration of SiO_2, Al_2O_3 and Fe_2O_3 was found to be 55.0, which was classified as a class C mineral admixture according to ASTM C618 (2019). This is in conformance with the specified standard. Table 4 below shows the test results in comparison to the ASTM standard (ASTM C618, 2019).

Table 4: Physical Properties of Mineral Filler

Property	Granite Dust	CDA
Specific gravity	2.63	2.56
Percentage Passing Sieve No 200 (0.075 mm) (%)	78.6	72.3

3.5marshal Stability Test

Table 5 and Figures 2, 3, 4, 5, 6 and 7 show the control results of stability, flow, unit weight, percent voids in compacted mineral aggregates (VMA), percent of air voids in each of the paving mixtures (Pa), and the void filled with bitumen (VFB) respectively.

Table 5: Marshal and Volumetric properties' results for HMA control samples

Bitumen by weight of mix (%)	Stability (kN)	Flow (mm)	Unit weight (g/cm^3)	VMA (%)	Pa (%)	VFB (%)
4.5	8.2	2.7	2.28	15.93	5.79	63.65
5.0	10.7	3	2.29	16	4.58	71.38
5.5	10.9	3.3	2.31	15.72	3.35	78.69
6.0	10.3	4.2	2.30	16.53	2.95	82.15
6.5	8.1	4.4	2.28	17.69	2.98	83.15

Figure 2 shows the plot of the stability of the control mix versus bitumen content. The graph shows that there is an increase in stability with increasing bitumen content with a peak at 5.5% bitumen content which corresponds to 10.9KN. Further increase in bitumen content shows a decrease in stability from the maximum stability. It is a well-known fact that higher bitumen content causes bleeding and loss of strength. The increased bitumen content introduced thicker films of bitumen thereby reducing the stiffness of the mix and making it susceptible to deformation. A similar result was obtained by (Murana et al., 2014).

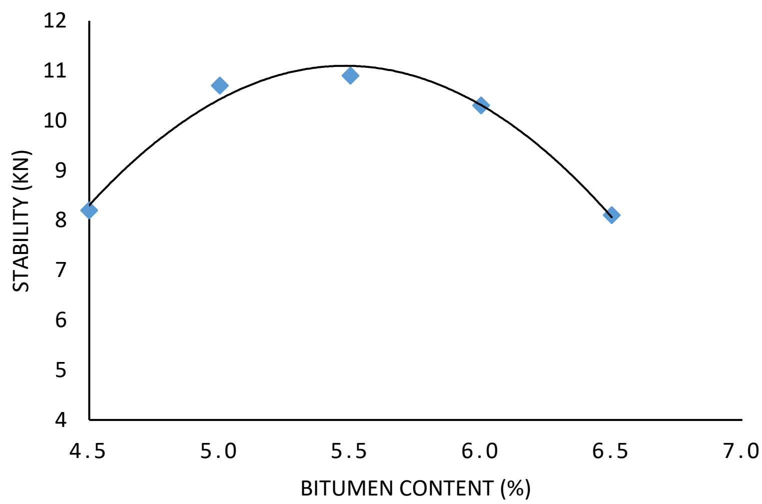

Figure 2: Variation of Stability with Bitumen Content

3.6 Variation of Flow with Bitumen Content

Figure 3 shows the graphical representation of flow of material against bitumen content. Iit can be seen that the flow steadily increases with an increase in bitumen content. According to Coleman (2002), flow is the displacement occurring during stability tests on samples. The increase in bitumen content reduces the interlocking properties between the aggregates making them prone to displacement.

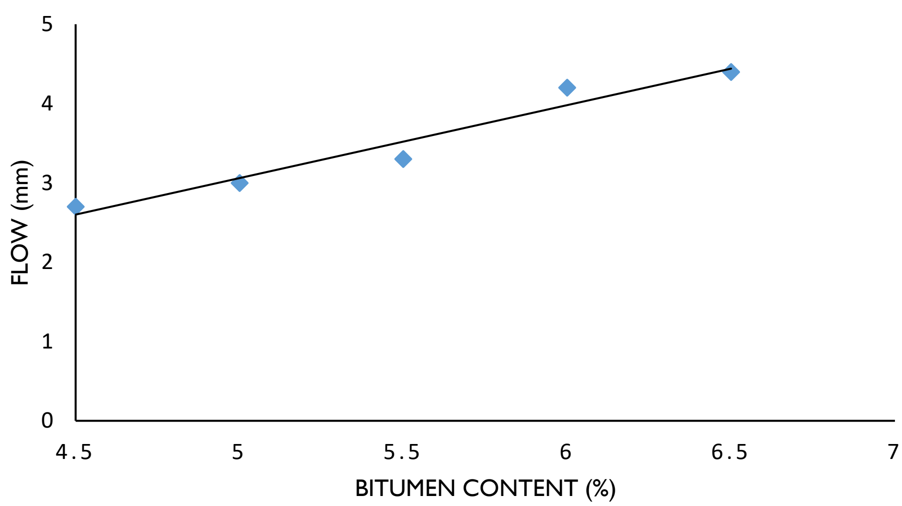

Figure 3: Variation of flow with Bitumen Content

3.7 Variation of Unit Weight with Bitumen Content

Figure 4 shows the plot of unit weight against varying bitumen content. The unit weight of the specimen was observed to increase with the continuous addition of bitumen content. From the maximum unit weight, the unit weight decreases with additional bitumen content. A similar pattern was obtained by Murana and Sani (2015).

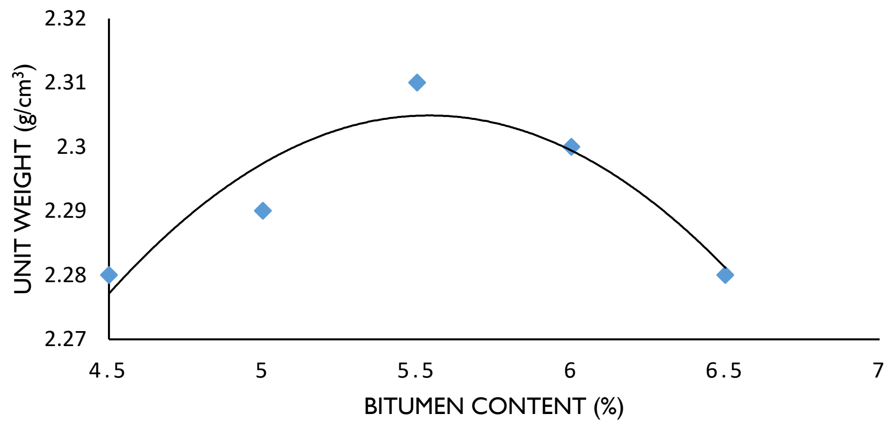

Figure 4: Unit Weight versus Bitumen Content

3.8 Variation Voids in Mineral Aggregate (VMA) with Bitumen Content

Figure 5 shows the graphical representation of the relationship between voids in a mix of mineral aggregates (VMA) and bitumen content. It can be observed that VMA decreases with an increase in bitumen content. This can be attributed to the presence of bitumen in the voids of the aggregate.

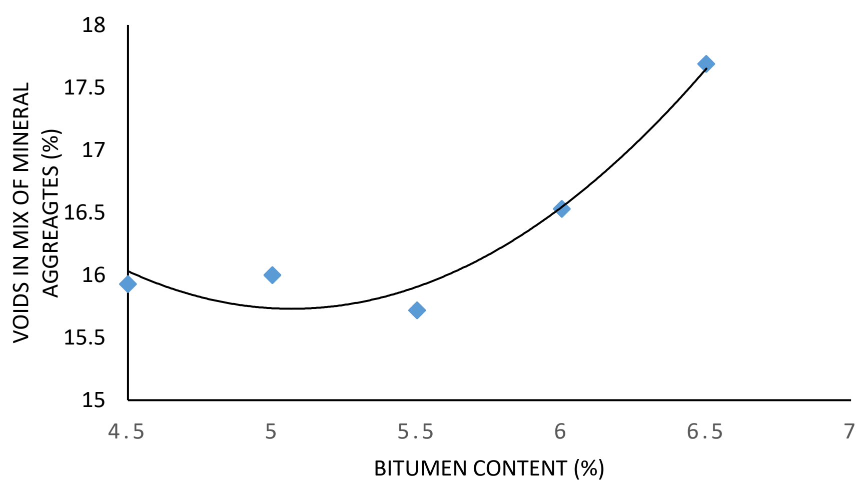

Figure 5: VMA versus Bitumen Content

3.9 Variation of Voids in the Mix With Bitumen Content

Figure 6 shows the graphical representation of voids in the mix against bitumen content. Voids in the mix are the small air voids between aggregates coated with bitumen. From the Figure, the voids decrease with an increase in bitumen content. This implies more bitumen content filled the spaces between the bitumen-coated aggregates. A similar pattern was observed when palm kernel ash was used to modify HMA (Nwaobakata and Agunwamba 2014).

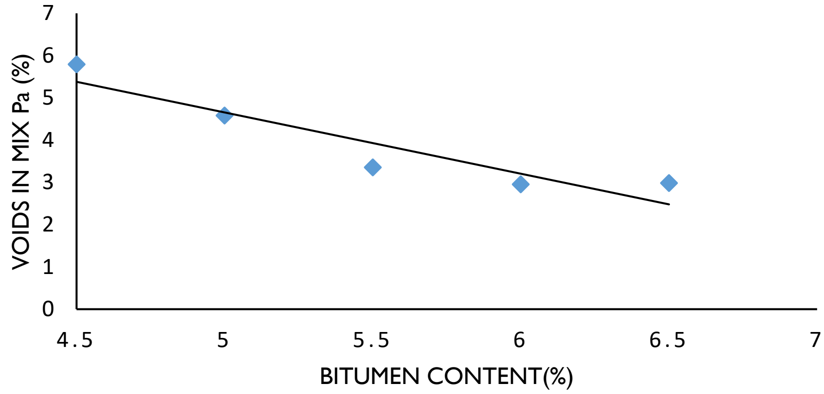

Figure 6: Void in Mix Versus Bitumen Content

3.10 Variation of Voids Filled with Bitumen (VFB) with Bitumen Content

Figure 7 shows the relationship between voids filled with bitumen against varying bitumen content. The Figure illustrates that the percentage of void filled with bitumen increases with increasing bitumen content.

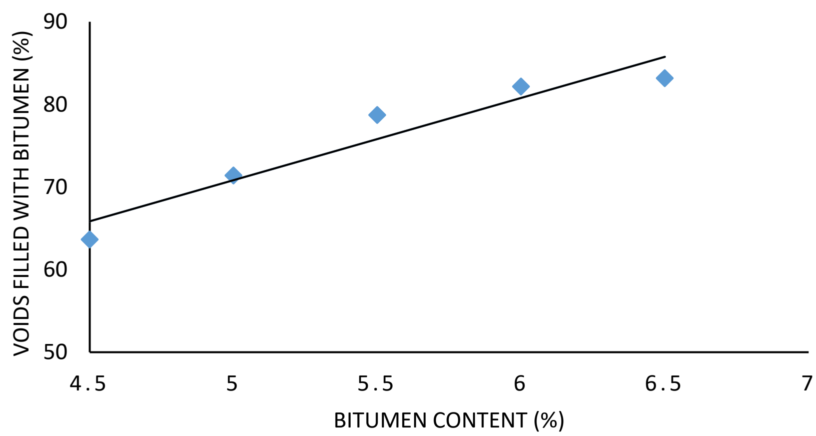

Figure 7: VFB versus Bitumen Content

3.11 Effect of CDA on Stability

Figure 8 depicts the relationship between stability against bitumen content at varying cow dung ash (CDA) content. As can be seen from the Figure, stability increases with increase in bitumen and CDA content after which were found to decrease at 6.5% bitumen content. According to (Nwaobakata and Agwunwamba 2014), additional filler to the optimum filler content reduces contact between aggregates, therefore, lowers the stability.

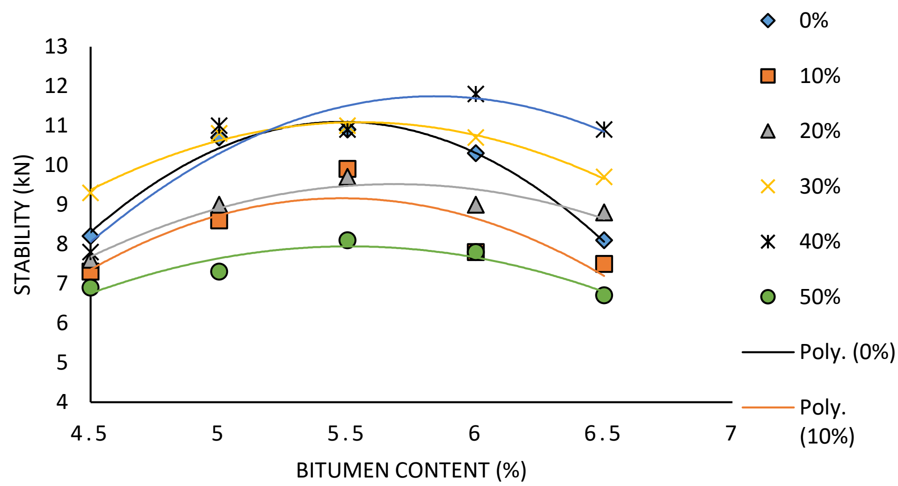

Figure 8: Stability Versus Bitumen Content at varying CDA content.

3.12 Effect of CDA on Flow

Figure 9 represents flow against bitumen with increase in CDA content. From the Figure, it shows that the flow was found to increase with increase in CDA content which was directly proportional to increasing bitumen content. From this, it can be deduced that increase in mineral filler increases flow. This is in agreement with the work conducted by (Modupe et al. 2019).

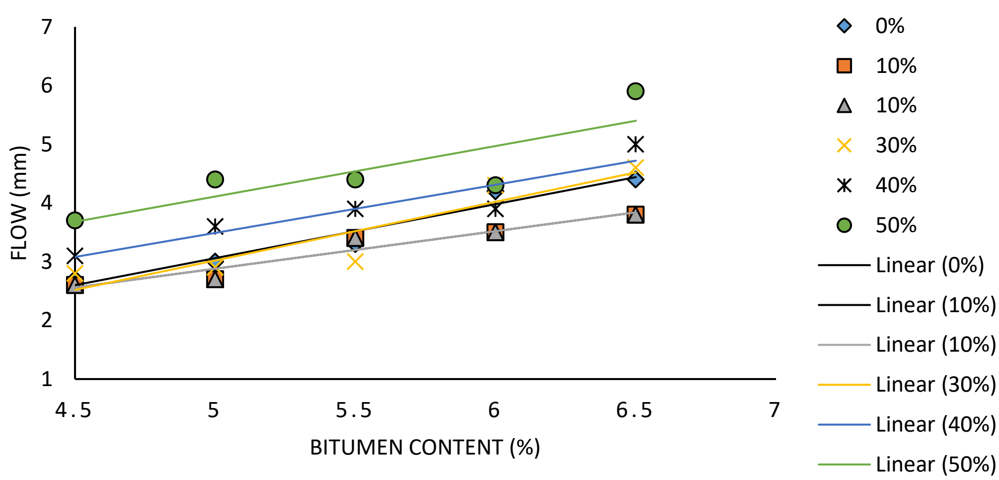

Figure 9: Flow versus Bitumen Content at varying CDA content.

3.13 Effect of CDA on Unit Weight

Figure 10 illustrates the relationship between the unit weight and bitumen content at varying CDA content. From the Figure, the unit weight was observed to increase with increase in bitumen content and increase in CDA content. It was observed that at 4.5% bitumen content, the unit weight of the control at 2.28 mm was higher than the modified CDA HMA. This implies that more filler stiffens the mix by filling the voids and reduces the permeability. The work of Murana, Emekaobi, and Laraiyetan (2019) confirms that increased bone ash in HMA reduces unit weight.

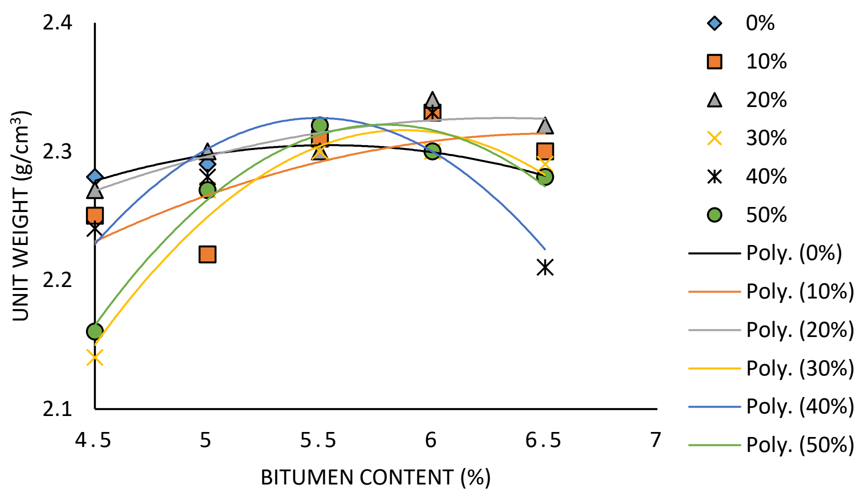

Figure 10: Unit Weight versus Bitumen Content at varying CDA content.

3.14 Effect of CDA On Voids In Mineral Aggregates (VMA)

Figure 11 represents the relationship between VMA, bitumen and CDA content. A decrease in VMA with additional filler was observed, which was followed by an increase in VMA after reaching a minimum value. It can be deduced that an increase in CDA decreases the void in the mineral aggregate of the mix. Wagaw, Quezon, and Geremew (2018) obtained a similar trend when brick dust was used to modify HMA.

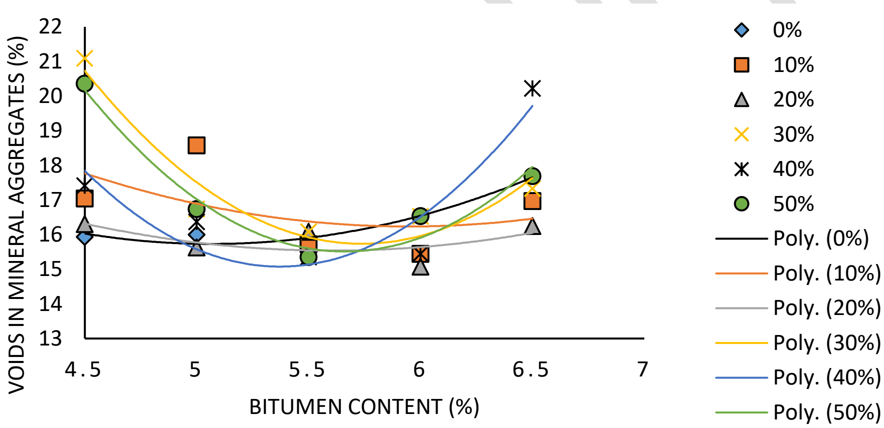

Figure 11: VMA versus Bitumen Content at varying CDA content.

3.15 Effect of CDA on voids in Total Mix (PA)

Figure 12 shows the relationship between air voids in the CDA modified mix at varying bitumen content. Introducing CDA at 4.5% bitumen content showed an increase in air void of the control mix from 5.79% to 7.02% for the modified mix. The air voids were observed to reduce with increase in CDA. This pattern of the result was also obtained by Vasudevan (2017) when coal bottom ash was used to modify HMA.

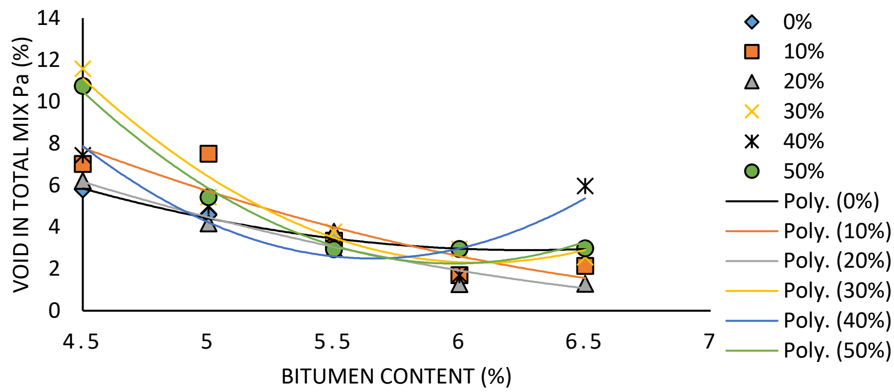

Figure 12: Void in Total Mix versus Bitumen Content at varying CDA content.

3.16 Effect of CDA on Voids Filled with Bitumen

Figure 13 represents the relationship between voids filled with bitumen, bitumen content and CDA content. The values obtained show an increase in the percentage of void filled with bitumen which is directly proportional to bitumen content and CDA content. Similar pattern was also observed by Murana, Emekaobi, and Laraiyetan (2019).

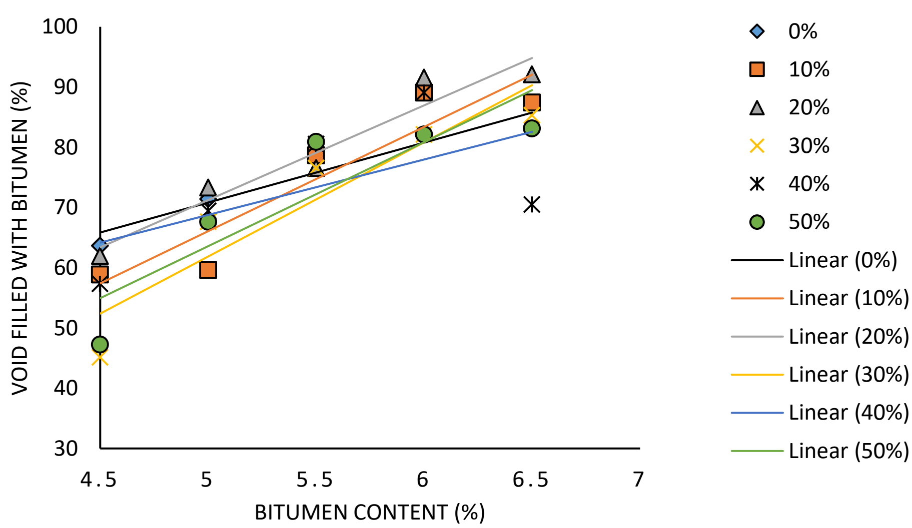

Figure 13: VMA versus Bitumen Content at varying CDA content.

5. Conclusion

The conclusions deduced from this research are as follows:

1. The results of the test conducted on the constituent materials such as the aggregates and bitumen show that they satisfy the limits specified by the Federal Ministry of Power, Works and Housing (FMWH 2016). Therefore, this implies the materials can be used in producing hot mix asphalt.
2. The chemical and physical properties of Cow Dung Ash (CDA) were found to be satisfactory and can be used as filler in hot mix asphalt.
3. The results of the stability, flow and volumetric properties were found to be satisfactory as accepted by Nigerian General Specifications for Roads and Bridges, 2016.

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