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Volumetric Properties of Cow Bone Ash (CBA) Filler-Based Asphaltic Concrete Using Aggregates from Different Sources

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A B S T R A C T

Road infrastructure in Nigeria is in a state of decay arising from various factors such as construction with low quality materials and poor maintenance. Therefore, there is a need to ensure that the materials used for construction are of the required standards and the alternative construction materials are available to reduce construction cost. In this research work, Cow Bone Ash (CBA) was used as filler in producing the asphaltic concrete samples. Then, Marshall Stability and flow test were carried out on the asphaltic concrete samples. The materials used in this study include 60/70 penetration grade bitumen, river sand, and crushed granites obtained from three selected quarries with various tests carried out to determine their suitability for use. The lower quality aggregates, based on the tests carried out on the aggregate samples, have shown to negatively affect the asphaltic concrete. The aggregate samples had average elongation index of 33.9% and abrasion index of 29.6%, while the asphaltic concrete samples had Marshall Stability values (with and without) CBA of 36.99 KN and 46.84 KN, respectively. The results of the flow test on the asphaltic concrete samples gave 8.29 mm with CBA and 14.71 mm without CBA. The study also reveals that asphaltic concrete samples produced without CBA as fillers are better as they have an average stability value of 15.61 KN and average flow value of 4.90 mm than those produced with CBA which have average stability value of 12.36 KN and an average flow value of 4.90 mm. Statistical analysis shows that the source of aggregate, significantly affects the properties of asphaltic concrete.

1. Introduction

Road infrastructure in Nigeria is in a state of disrepair. This arises from various vices such as the roads being built with low quality materials, lack of funds to adequately finance the roads during the construction and maintenance phase, road congestion, poor state of other means of transportation. Regardless of the state of the roads, there is still heavy reliance on the road network as the major means of transportation in Nigeria. All these have contributed to making most of the paved road networks in the county to lose their asphalt surface and making them characterized by uneven surfaces, potholes, raveling alongside many other pavement defects. This poor condition of the countries road network has contributed significantly to the high rate of road accidents in the country, productive man-hours being lost in traffic, security challenges as the reduced traffic movements at the bad spots have paved ways for robberies among other vices that does not project the country in positive light according to Adanikin

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et al. [2]. Asphaltic concrete refers to a mixture of coarse and fine aggregates, stone dust, mineral fillers, and binder (bitumen). Aggregate is a broad category of coarse particulate materials used in construction, including sand, gravel, unscreened and screened crushed stone, slag, recycled concrete, and geosynthetic [15]. Zoorob and Suparma [17] reveals that the amount of aggregate in asphalt paving mixtures is generally 90 to 95 percent by weight or 75 to 85 percent by volume, and almost 12,500 tons of aggregates are being consumed for each kilometer of flexible pavements and this shows the importance of aggregates in asphaltic concrete production.

Waste disposal remains a huge challenge in developing countries due to the inefficient disposal system. Nwaobakata and Agwunwamba [12] stated that the vast quantities of waste accumulating in stockpiles and landfills globally are causing disposal problems that are both financially expensive and constitute the environmental hazards. One of such waste whose generation runs into millions of tones in Nigeria is Cow Bone as revealed by Falade et al. [5]. Sustersic et al. [14] reveals that asphaltic concrete layers when exposed to different weather conditions and high energy radiations of mechanical stressing, the long-term degradation of the asphaltic binder is often initiated. However, the use of pozzolanic materials such as Cow Bone Ash (CBA) can be employed to reduce the asphaltic concrete degradation. A productive use of the cow bone ash is to recycle and use it as a filler in asphaltic concrete considering its pozzolanic characteristics which offers improved workability and sulphate resistance, reduced bitumen bleeding and lower heat of hydration amongst other advantages which will significantly improve properties of asphaltic concrete in road construction.

The rising cost of road construction, depletion of conventional materials, environmental degradation has necessitated research into alternative materials such as agricultural and industrial wastes in the production of asphaltic concrete to determine their mechanical properties and effectiveness in producing viable roads, reducing construction costs and reducing their negative environmental impact. Oyedepo [13] studied the use of Crushed Oyster (COS) and Palm Kernel Shell (CPKS) using Marshall Stability test and revealed that partial replacement of fine aggregates with COS and CPKS in bituminous mix is suitable for light traffic roads and can be used to reduce construction costs. Mohammed et al. [11] studied the properties of asphaltic concrete by partial replacement of fine aggregate (sand) with crushed palm kernel shell and posit that 10% and 50% replacement of fine aggregate by weight with crushed palm kernel shell adequately supports the requirements for asphaltic concrete. Liu et al. [8] evaluated the use of Organo Montmorillonite Nano clay as an alternative modifier to sustain durability of asphalt pavement and concluded that it improves the short-term aging resistance of base bitumen in asphaltic concrete. Bakis et al. [4] investigated the use of waste foundry sand as replacement in asphalt concrete mixtures and their result showed that replacement of 10% aggregates with waste foundry sand was most suitable for asphalt concrete mixtures. Abbas et al. [1] stated that Ground Granulated Blast Furnace Slag (GGBFS) has been shown to improve properties of asphaltic concrete mixes by more than 40%. Juan et al. [7] stated that the Indirect Tensile Stress (ITS) of hot-mix asphalt increased with increasing recycled concrete aggregates. Wojcieh et al. [16] in their study revealed that properties of aggregates have a direct impact on their use in asphaltic concrete pavements. Properties such as resistance to grinding and adhesion to asphaltic binder are important parameters that are influenced by nature of coarse aggregates and admixtures in road construction.

Mirkovic et al. [10] revealed a satisfactory volumetric composition can be achieved by adding fly ash, while the bulk density and voids of the mineral and asphalt mixture generally depend on the type of fly ash and its content. Hossain et al. [6] posit that 25% fly ash and 75% stone dust by total weight of filler satisfy the mix design criteria for medium traffic condition. Manish et al. [9] revealed that the Saw Dust

Ash (SDA) can partially replace cement at 10% SDA and at 5.5% bitumen content. The literatures reviews show the relevance of the study.

This study thereby seeks to study the use of CBA as a filler against conventional fillers in asphaltic concrete mixes; fillers in asphaltic concrete mixes have long been used as stiffening, extending/void filling materials in asphaltic concrete depending on their size and type. The study is also combining both experimental and statistical techniques. To achieve this, studies on the bitumen, filler (CBA), fine and coarse aggregate samples and the asphaltic concrete produced will be carried out using Marshall Stability and flow test by varying the coarse aggregate sources.

2. Materials and Method

The materials used in this study include 60/70 penetration grade bitumen, river sand free from deleterious materials and crushed granites obtained from three selected quarries within Ondo State, Nigeria. The three selected quarries among many others presents a good representation of the type of rock that is obtainable in the area. The selections were made based on the extent of patronage and rate of production of aggregates from the quarries as compared to others within the same state and sampled opinion. The details of the selected quarry are listed in *Table 1*.

Table 1. *Selected quarries for test samples.*

S/N	State	Sample ID	Description of Location
1	*Ondo State*	*Sample A*	*Ore, Ondo state*
2	*Ondo State*	*Sample B*	*Owo Road, Akure, Ondo State*
3	*Ondo State*	*Sample C*	*Ore, Ondo State*

The sampling of aggregates for tests were done at the selected quarries following the appropriate sampling procedure in the British Standard (BS). The samples were investigated in a specialized laboratory to determine the physical and mechanical properties of the aggregates. The knowledge of the physical properties was used in addition to evaluate the result of the mechanical properties of the aggregates.

The following tests were conducted on all the samples: (i) Aggregates Loose Density Test (BS 812: 102), (ii) Water Absorption Test (BS 812-102: 1989), (iii) Flakiness Index Test (clause 5 of BS 812-102: 1989), (iv) Elongation Index Test (clause 5 of BS 812-102: 1989), (v) Aggregate Crushing Value (ACV) Test (clause 5 of BS 812-102: 1989), (vi) Aggregate Impact Value (AIV) Test (clause 5 of BS 812-102: 1989), and (vii) Aggregate Abrasion Value (AAV)-Los Angeles Test (clause 5 of BS 812-102: 1989).

The CBA was obtained from an abattoir in Akure, Ondo state. It was sundried, milled with an industrial grinding machine, burnt to ash in an electric furnace (Carbolite GPC 12/65) at 800°C for 90 minutes and then sieved with sieve No. 200 aperture to produce the ash which is used as filler in the asphaltic concrete mixture. *Fig. 1* shows the heap of cow bone at the abattoir. *Fig. 2* shows extrusion of the asphaltic concrete, respectively.

In the Marshall Test, the heights of the samples were measured and specimens were immersed in a water bath at 60°C for 35±5 minutes. Specimens were removed from the water bath and quickly placed in the Marshall loading head. The Marshall stability of mix is defined as a maximum load carried by a compacted specimen at a standard test temperature of 60ºC. The flow value is deformation of the Marshall Test specimen undergoes during the loading up to the maximum load, 0.25 mm units. *Fig. 3* and *Fig. 4* show the asphaltic concrete samples with and without CBA from the selected quarries, respectively.

Fig. 1. *Heap of cow bones.*

Fig. 3. *Extruding the asphaltic concrete.*

Fig. 3. *Asphaltic concrete samples with CBA.*

Fig. 4. *Asphaltic concrete samples without CBA.*

3. Results and Discussion

The results of all the laboratory tests carried out on each of the three quarries aggregates samples (A, B, C) are tabulated in *Table 2*.

Table 2. *Summary of tests on the aggregates.*

Source of Aggregates (Quarry)	Loose Density of Aggregates (Kg/dm^3)	Water Absorp-tion (%)	Flakiness Index (%)	Elongation Index (%)	ACV Test (%)	AIV Test (%)	AAV Test (%)
Sample A	*1.42*	*0.29*	*21*	*44.5*	*23.3*	*10.64*	*30.8*
Sample B	*1.38*	*0.37*	*16*	*27.5*	*26.5*	*15.93*	*28.8*
Sample C	*1.37*	*0.30*	*29.5*	*29.6*	*22*	*12.02*	*29.3*
Permissible limit-standard specification	*Min is 0.75kg/dm^3 Max is 1.867kg/dm^3*	*≤1.0% BS 812-109: 1990*	*≤25% BS 812-105.1: 1989*	*≤35% BS 812-105.2: 1990*	*≤30% BS 812-110: 1990.*	*≤35% BS 812-112: 1990*	*≤30% BS 812-113: 1990*

Table 2 presents a summary of tests carried out on the aggregates. The loose density of aggregates test shows that all the aggregates exceed the minimum standard (0.75 kg/dm^3) and fall below the maximum standard (1.867 kg/dm^3). The aggregates also all satisfy the water absorption limit as their values are below 1.0%.

The result of ACV test obtained shows that all of the aggregates tested have their ACV values less than 30% which is in conformity with the requirement of "Not more than 30% for surface or wearing course". The lower ACV is better aggregated, therefore, with the ACV of Sample B being the highest with 26.5% it is adjudged the least efficient based on ACV while that of Sample C, the lowest with 22% is adjudged the most efficient aggregate based on ACV.

The AIV test results show that the aggregates fall within the "very tough" rating with the aggregates from Sample A having the highest rating of 10.64%. The AIV test indicates that when vehicles have impact on the road surface during movement, aggregates from Sample A will break down the least (10.64%) while aggregates form Sample B will break down the most (15.93%).

The AAV test shows that the aggregates from Sample A with AAV value of 30.8% exceeds the permissible limit of 30% while that of others are within the permissible limit. All these shows that the aggregates are considered satisfactory for road surfacing/wearing course construction.

Tests carried out on the bitumen sample as shown in *Table 3* reveal that the bitumen is of penetration grade 60/70 with a penetration value of 66 mm making it suitable for road construction and production of asphalt pavements.

Table 3. *Summary of tests on bitumen.*

Test	Obtained Value	Standard Values
Penetration	*66 mm*	*60/70 mm (ASTM D5)*
Specific gravity at 25 °C	*1.04 °C*	*1.01 – 1.06 (ASTM D70)*
Water in bitumen	*3%*	*2% (IS:1211-1978)*
Flash point	*282 °C*	*250 (ASTM D92)*
Fire point	*313 °C*	*300 °C -320 °C*
Ductility at 25 °C	*101 mm*	*100 (ASTM D113)*
Softening point	*49 °C*	*49 °C -56 °C (ASTM D36)*
Angular frequency at 60 °C	*1.6*	
Angular frequency at 120 °C	*1.6*	
Viscosity at 60°C	*0.65 mPas*	
Viscosity at 120 °C	*0.53mPas*	

The specific gravity of the bitumen at 25 °C is 1.04 °C; a 3% water in bitumen value is obtained though this exceeds the 2% by weight as specified by IS:1211-1978; the bitumen is still considered good for use. The water in bitumen is vital as high-water content hinders bonding between the bitumen, aggregates and fillers.

The flash point thereby reflects the lowest temperature (282°C) at which the vapor of the bitumen momentarily catches fire in the form of a flash under specified test conditions while the fire point is the lowest temperature (313°C) under specified test conditions at which the bituminous material gets ignited and burns. The ductility which is a function of the bitumen deformation or elongation without breaking is 101mm. The softening point which denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test was obtained as 49 °C which is within the acceptable limit according to ASTM D36.

Marshal Stability results of the study is shown in *Table 4* and *Fig. 5*.

Table 4. *Marshall stability test.*

Source of Aggregate	Stability (KN)	Flow (mm)
Sample A with CBA	*11.25*	*3.13*
Sample A without CBA	*14.06*	*4.16*
Sample B with CBA	*13.94*	*3.41*
Sample B without CBA	*17.28*	*5.86*
Sample C with CBA	*11.88*	*1.75*
Sample C without CBA	*15.50*	*4.69*

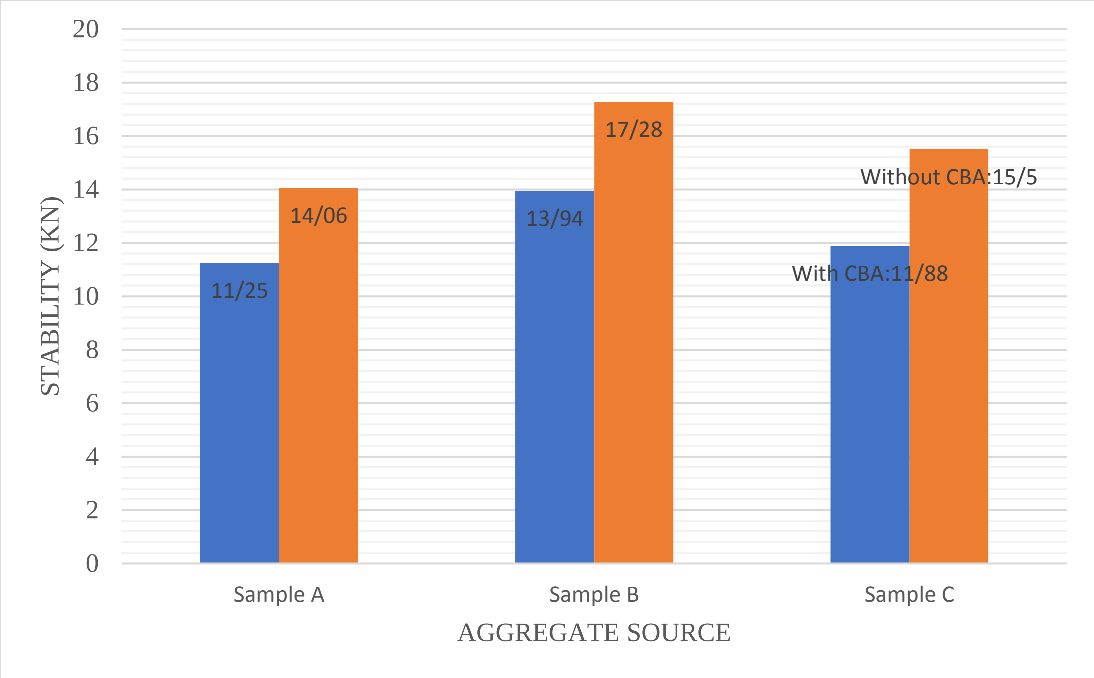

Fig. 5. *Marshall stability test results of the aggregates with and without CBA.*

The study reveals that the stability of all the asphaltic concrete samples with and without CBA satisfies the Asphalt Institute [3] specifications for stability of asphaltic concrete (Not less than 3.5 KN). Considering the higher stability of the asphaltic concrete, better samples from Sample B had the highest values for the asphaltic concrete produced with CBA (12.94 KN) and without CBA (17.28) that considered the best. Lower quality aggregates based on the test on aggregates have shown to negatively affect the asphaltic concrete as they will break down during the Marshall Stability test. These aggregates with poor quality affect their binding with bitumen in the asphaltic concrete under continuous traffic loading and weathering action.

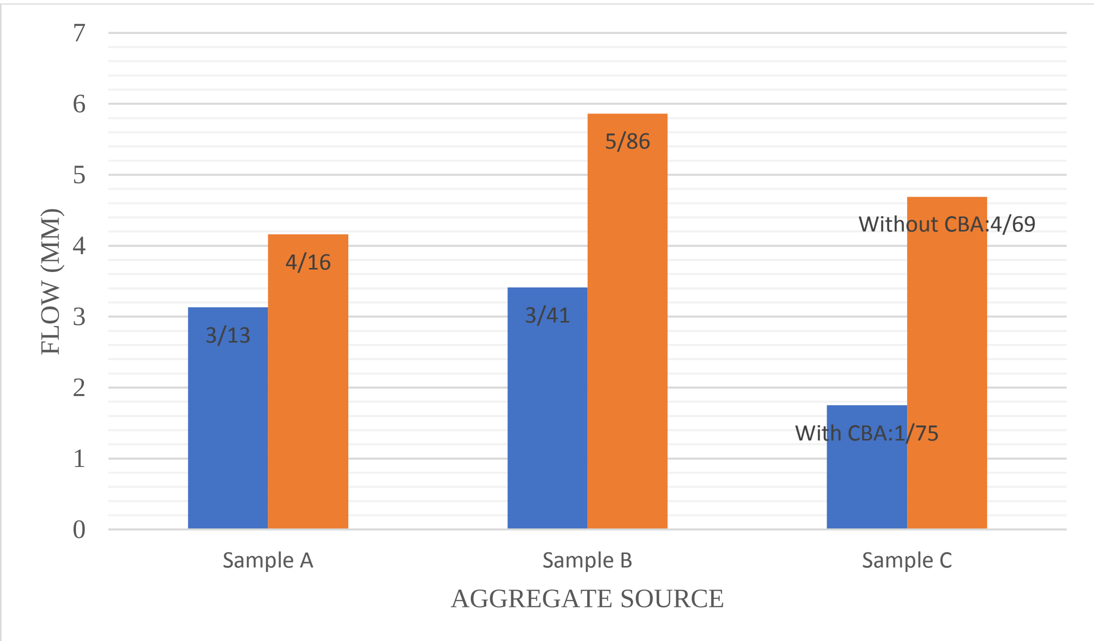

Fig. 6. *Marshall flow test results of the aggregates with and without CBA.*

Findings of the study as shown in *Table 4* and *Fig. 6* reveal that the flow of the asphaltic concrete samples with and without CBA satisfies the Asphalt Institute specifications for stability of asphaltic concrete (Not less than 2 mm) except the asphaltic concrete produced with CBA from Sample C. Sample B had the highest values for the asphaltic concrete produced with CBA (3.41 mm) and without CBA (5.86 mm) that considered the best.

Table 5 and *Fig. 7* show the findings of the study and reveal that asphaltic concrete samples produced without CBA as fillers are better as they have an average stability value of 15.61 KN and average flow value of 4.90 mm than those produced with CBA which has an average stability value of 12.36 KN and an average flow value of 4.90 mm.

Table 5. *Average Marshall stability test values with and without CBA.*

Source of Aggregate	**Stability (KN)**	**Average Stability (KN)**	**Flow (mm)**	**Average Flow (mm)**
Sample A with CBA	*11.25*		*3.13*	
Sample B with CBA	*13.94*	*12.36*	*3.41*	*2.76*
Sample C with CBA	*11.88*		*1.75*	
Sample A without CBA	*14.06*		*4.16*	
Sample B without CBA	*17.28*	*15.61*	*5.86*	*4.90*
Sample C without CBA	*15.50*		*4.69*	

The addition of CBA as a filler has shown that negatively affects the stability of the asphaltic concrete from the different aggregate sources and reduces the structural resistance of the road pavement to traffic loads. This could be due to its organic nature though using it still falls within the acceptable specification for use in road pavement construction.

Table 6 presents the statistical analysis of findings using ANOVA. The analysis shows that the source of aggregate significantly affects the properties of asphaltic concrete at 0.012274 significance level. Also, the F value (9.987933) is greater than the F crit (5.050329) showing the significance. Furthermore, analysis indicates that Marshall Stability values is significantly affected by the aggregates when they are admixed with or without CBA at 3.59E-06 level of significance. With the F value (484.843) greater than F crit (6.607891), the study reveals the significance of CBA in asphaltic concrete Marshall Stability values.

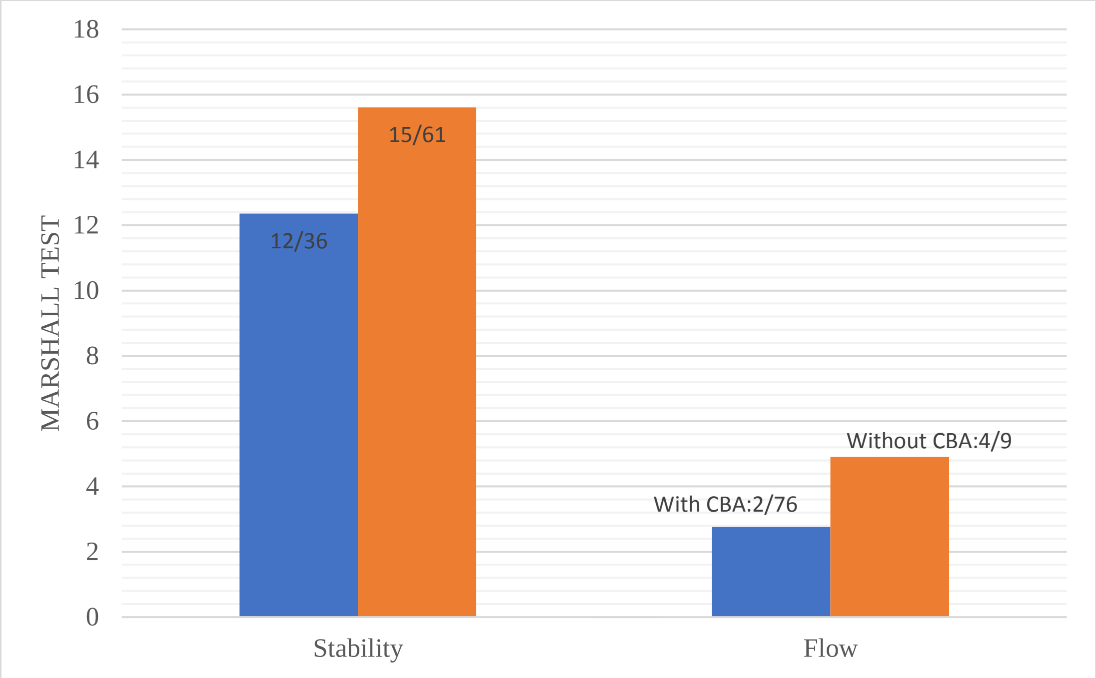

Fig. 7. *Average marshall stability test values with and without CBA.*

Table 6. *Statistical analysis of findings using ANOVA.*

SUMMARY	**Count**	**Sum**	**Average**	**Variance**		
Sample A (With CBA)	*2*	*14.38*	*7.19*	*32.9672*		
Sample A (Without CBA)	*2*	*18.22*	*9.11*	*49.005*		
Sample B (With CBA)	*2*	*17.35*	*8.675*	*55.44045*		
Sample B (Without CBA)	*2*	*23.14*	*11.57*	*65.2082*		
Sample C (With CBA)	*2*	*13.63*	*6.815*	*51.30845*		
Sample C (Without CBA)	*2*	*20.19*	*10.095*	*58.42805*		
Stability	*6*	*83.91*	*13.985*	*5.01423*		
Flow	*6*	*23*	*3.833333*	*1.992427*		
Source of variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Source of aggregate	*31.84494*	*5*	*6.368988*	*9.987933*	*0.012274*	*5.050329*
Marshall stability	*309.169*	*1*	*309.169*	*484.843*	*3.59E-06*	*6.607891*
Error	*3.188342*	*5*	*0.637668*			
Total	*344.2023*	*11*				

4. Conclusion and Recommendations

This study concludes that the asphalt concrete with CBA will be less resistant to deformation caused by traffic loadings than those without CBA. This could be as a result of the CBA being an organic component which used as a filler reduces the asphaltic concrete ability to withstand higher stress as it fills the voids in asphalt concrete, thereby, contributing to the asphaltic concrete lower stability and flow compared to those without CBA. The CBA can also be said that have produced the lower contact points between aggregates, hence, resulting in lower stability. The study therefore invariably revealed that better aggregates used in road construction, better asphaltic concrete is produced. Secondly, CBA as a filler does not increase the stability and flow of an asphaltic concrete though it still produces asphaltic concrete good for use in low trafficked roads. It is therefore recommended that adequate tests be carried out on aggregates used in bituminous mix as they affect the stability and flow of the asphaltic concrete and in a large extend, they determine the durability and maintenance of the road pavements.

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