Journal of Civil Engineering, Science and Technology
Volume 15, Issue 1, April 2024, 40 – 49

EVALUATION OF LOCUST BEAN POD ASH AS MINERAL FILLER IN HOT MIX ASPHALT

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Date received: 15/12/2023 Date accepted: 11/03/2024
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DOI: 10.33736/jcest.6352.2024

Abstract — An increase in the consumption of agricultural products generates large quantities of waste daily. The husks of the locust bean seeds when removed from the plant are littered in the environment which negatively affects the environment. In this research, locust bean pod ash (LBPA) was used as a mineral filler in hot mix asphalt. Physical and chemical tests were done on the aggregate, bitumen and LBPA, showing adequacy for use in asphalt concrete production. All tests were conducted in accordance with relevant standards. LBPA was admixed with granite dust from 0–50% (at intervals of 10%) with varying bitumen content from 4–7% (at 0.5% intervals). For this experiment, the Marshall mix design method was used. The Marshall stability of samples containing LBPA improved by 19%, from 8.16kN to 9.67kN. Similarly, Marshall flow decreased by 19% from 3.4 mm to 2.75 mm. The density-void analysis of the asphalt samples also revealed an improvement. The microstructural examination revealed an enhanced structural arrangement due to the flocculation of the LBPA particles. Overall, the hot mix asphalt samples meet the Federal Ministry of Works and Housing specifications for flexible pavement-wearing courses. It was determined by the study that adding 40% LBPA with 60% granite dust at 5% bitumen content would improve the performance of hot mix asphalt.

Keywords: bitumen, filler, granite dust, locust bean pod ash, Marshall property

1.0 INTRODUCTION

A safe and efficient highway transportation system is an important element for sustainable national growth as it is crucial to the socio-economic integration of the nation. Roads are the backbone of the land transportation network, as they account for most modes of transportation which subsequently support economic growth and promote social activities. It is the duty of highway engineers to design, construct and maintain highway roads.

According to the Federal Ministry of Works and Housing [1] roads are the most dominant travel mode accounting for about 90% of passengers and goods transport in Nigeria. Road pavements are divided into two categories: rigid pavement and flexible pavement [2]. Flexible pavements are typically constructed in layers of subgrade, subbase, base course and then overlaid with a cementitious-bound material. The cementitious materials used are asphalt or tar [3]. Asphalt materials have been used for road construction and maintenance since the end of the nineteenth century. They are the most common and available materials for quality road surfacing [4]. Supplementary Cementitious Materials (SCM) are often incorporated in asphalt concrete mixes to reduce cement contents, improve workability, increase strength and enhance durability [5]

In recent years, Nigeria has experienced an increase in traffic volume. This increase causes the pavements to be exposed to higher stresses. Higher density of traffic in terms of commercial vehicles, overloading of trucks, and significant variation in daily and seasonal temperature of pavements have been responsible for the development of distresses such as raveling, rutting, and fatigue failures of bituminous surfaces [6]. Murana and Sani [5] stated that there have been several potential uses of crop waste material for pavement construction. The availability of various local materials as agricultural wastes has shown great suitability for use for road pavements and asphaltic concrete production [7].

Locust Bean Pod Ash (LBPA) is the product of the combustion of locust bean pods in an incinerator at a controlled temperature or an open-air burning. The solid residue after the combustion process is sieved through a set of standard sieves [8, 9]. For a mineral filler material used in hot mix asphalt, the materials pass through sieve No. 200 (aperture size 75 um).

Mineral fillers play a significant role in the engineering properties of hot mix asphalt, with particular reference to air voids, and voids in mineral aggregate. Filler also increases the stiffness of asphaltic mixtures and affects workability, moisture resistance and ageing characteristics of the hot mix asphalt mixes [10]. Numerous researchers have attempted to look into the possibility of using a variety of waste products—such as cement, fly ash, pond ash, stone waste, sawdust ash, rice husk ash, sewage sludge ash, glass powder, ceramic dust, brick dust, marble dust, coal waste, metakaolin, and vitrified polish waste—as fillers in the production of hot mix asphalt [11].

2.0 MATERIALS AND METHODS

2.1. Materials

The materials used for this experiment were:

(i) Bitumen grade 60/70

(ii) Coarse and fine aggregate

(iii) Granite dust

(iv) LBPA,

The bitumen, coarse and fine used in this experiment were sourced from Mother CAT Construction Company, located along the Zaria-Funtua express road, Zaria, Kaduna State. The LBPA was sourced from the Zaria local government area of Kaduna State. The LBPA was crushed, burned under controlled conditions and later calcined at 70°C for 2 hours, the residual was sieved with BS No. 200 (*75*µm).

2.2. Methods

Tests conducted on bitumen were:

(i) Penetration Test [12]

(i) Ductility Test [13]

(ii) Softening Point Test [14]

(iii) Flash and Fire Point Test [15]

(iv) Specific Gravity Test [16]

(v) Solubility Test [17]

Tests conducted on the fine and coarse aggregate were:

(i) Aggregate Impact Value Test [18]

(ii) Aggregate Crushing Value Test [18]

(iii) Elongation Index Test [19]

(iv) Flakiness Index Test [20]

(v) Specific Gravity Test [21, 22]

(vi) Sieve Analysis Test [23]

Tests conducted on LBPA were:

(i) X-Ray Fluorescence (Xrf) Test [24]

(ii) Particle Size Distribution Test [23]

(iii) Specific Gravity Test [25]

2.2.1. Preparation and production of hot mix asphalt with blend of granite dust and LBPA

The preparation of the hot mix asphalt involved the selection of a good blend of aggregate and bitumen that met the required specification. Approximately 1200g of aggregates (including filler) were mixed together and heated to a temperature of 140°C, following which bitumen was added at varying percentages (4%, 4.5%, 5%, 5.5%, 6%, 6.5%, and 7%) by weight of the total mixture. The mixture was heated to a temperature of 160°C-170°C and stirred properly until a homogenous mixture was obtained. The prepared mix was immediately placed in a preheated mould of 4 inches (101.6mm) in diameter and 2.5 inches (63.5mm) in height and compacted with 75 blows to each side of the specimen. The briquette sample was allowed to cool for 25 minutes after compaction before being extracted from the mould. This procedure was done for the unmodified (i.e., hot mix with 0% LBPA) and modified mixes (i.e., hot mix with LBPA at 10%, 20%, 30%, 40% and 50%). The produced sample was taken to the laboratory for the stability-flow test and density-voids analysis.

3.0 RESULTS AND DISCUSSION

3.1. Results of the Test on Aggregate

The results of the preliminary test on the aggregates are shown in Table 1. The strength test, geometry test and specific gravity test are conducted on the coarse and fine aggregate to determine its suitability for use in the production of hot mix asphalt. The results obtained from the test conducted on the aggregate are within the specified code limits [26] thus satisfying the requirements of toughness, strength, density and abrasion.

Table 1 Physical Properties of Aggregates with Standard Specifications

Test	Unit	Test Value	FMWH 2016		Remark
			Min	Max	
Aggregate Crushing Value	%	27.2	-	30	Adequate
Aggregate Impact Value	%	25.8	--	30	Adequate
Elongation index		20.33	-	25	Adequate
Flakiness Index		23.50		25	Adequate
Specific Gravity (Coarse Aggregate)		2.6	2.6	2.9	Adequate
Specific Gravity (Fine Aggregate)		2.55	2.6	2.9	Adequate
Specific Gravity (Granite Dust)		2.74	2.6	2.9	Adequate
Specific Gravity (LBPA)		2.65	2.6	2.9	Adequate

The proportioning of the aggregates used in this research is shown in Table 2. The proportions that gave the required gradation were 50%, 45%, and 5%, for the coarse, fine aggregate and mineral filler respectively. The coarse aggregate was the material that passes a 12mm sieve and retained at 4.75mm; the fine aggregate was the material that passes 4.75mm; and the mineral filler was the material that passes 0.075µm and retained in the pan.

Table 2 Proportion of Aggregates

Aggregate Type	Size Range	Proportioned Mix Design (%)
Coarse Aggregate	12mm – 4.75mm	50
Fine Aggregate	4.75mm – 0.075µm	45
Mineral Filler	0.075µm - Pan	5

The aggregate gradation curve is shown in Figure 1. The proportioning was done by a trial-and-error method and was found to be satisfactory within the job mix of a wearing course as stipulated by the specification [26]. It is necessary to produce a satisfactory job mix, as aggregate grading is an important factor in determining the asphalt concrete packing density, interlocking capability and bonding [27].

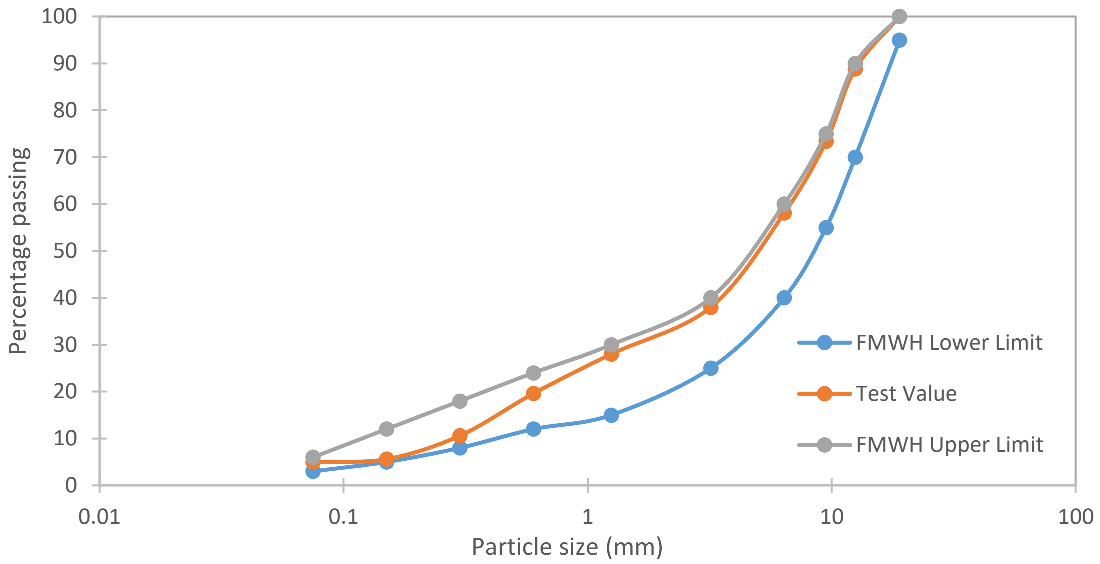

Figure 1 Aggregate gradation

3.1.1. Results of a chemical test on LBPA

The result of chemical composition test is shown in Table 3. Based on [28] classification, the LBPA can be grouped as class C pozzolan. This grouping is based on the summation of Silica (SiO_2) + Alumina (Al_2O_3) + Iron (Fe_2O_3). The summation of this oxide for LBPA was 71.53% and also based on the value of loss on ignition (6.21%). These results are similar to the values obtained by [29, 30]. The chemical composition of mineral filler plays a major role in the adhesion among filler, aggregates and bitumen. The activity of filler material can be divided into physical hardening and chemical adhesion [31]. The chemical activity is the chemical reaction between alkaline components of filler and bitumen acid. This is necessary to explain the effect of LBPA in hot mix asphalt.

Table 3 Chemical Composition of LBPA

Chemical	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	CaO	P_20_5	K_2O	LOI
%Composition	47.13	15.13	9.27	3.2	0.6	10.79	2.98	3.54	6.21

3.2. Tests on Bitumen

The results of the preliminary test on the bitumen are shown in Table 4. The results of the physical test on pure bitumen were found to be in line with [26] for 60/70 penetration grade bitumen and hence are considered suitable for use in the production of hot mix asphalt. A similar result was obtained by [32].

Table 4 Physical Properties of Bitumen with Standard Specifications

Test	Unit	Test Value	FMWH 2016		Remark
			Min	Max	
Penetration	0.1mm	66.2	60	70	Adequate
Ductility	cm	110		≥100	Adequate
Softening point	°C	53.9	48	56	Adequate
Flash Point	°C	255	250	-	Adequate
Fire point	°C	261		≥250	Adequate
Specific gravity	-	1.01	1.01	1.06	Adequate
Solubility (CCL_4)	%	100		≥99	Adequate

3.3. Effect of LBPA on Marshall and Volumetric Properties

3.3.1. Effect of LBPA on Marshall Stability

The variation in the Marshall Stability value with bitumen content and LBPA in is shown in Figure 2. It could be observed from Figure 2 that there was an increase with the addition of LBPA. The addition resulted in a 19% increase in stability value in comparison with the maximum stability of the control (0%) with a value of 8.16 kN corresponding with a bitumen content of 5.5% and the maximum stability of 9.67 kN recorded at 40% replacement with a corresponding bitumen content of 5%. This increase could be attributed to the uniform dispersal of LBPA in the mixture which created an active adhesion reaction between the bitumen and aggregate. Murana et al., [33] also stated that the addition of fillers increase the binder viscosity and thus increasing the stability values. The stability value for the modified and unmodified hot mix asphalt met the requirement for [26], which stipulates that the stability of hot mix asphalt intended for wearing course should not be less than 3.5 kN. This result is in agreement with previous research of [34] that studied the effect of cow bone ash as mineral filler in hot mix asphalt.

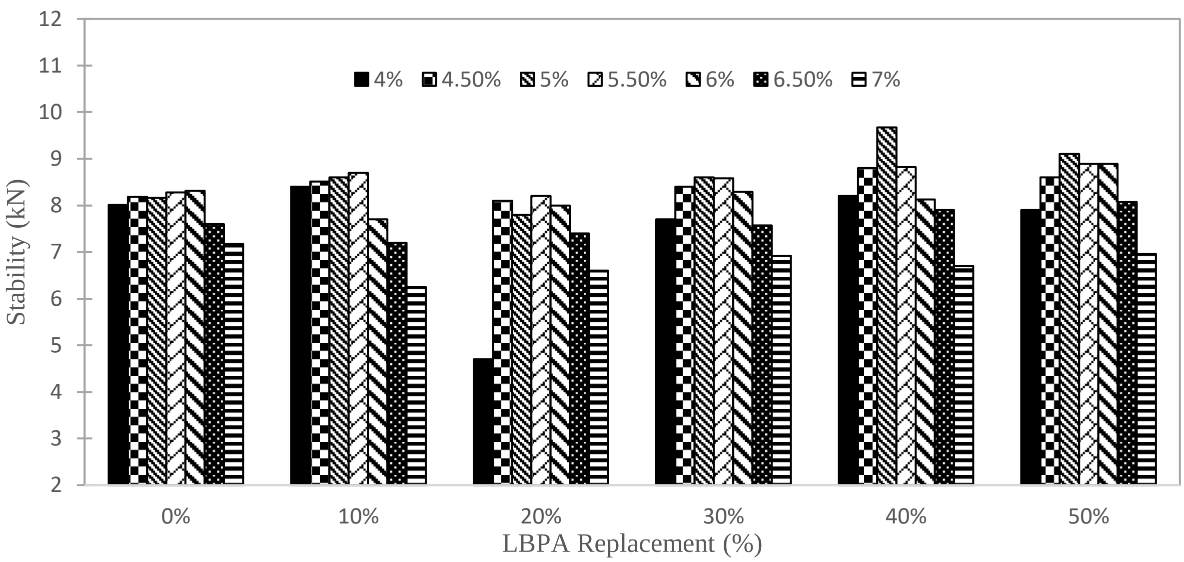

Figure 2 Variation of stability with bitumen content and LBPA

3.3.2. Effect of LBPA on Marshall Flow

The variation in flow value with bitumen content and LBPA is shown in Figure 2. It could be observed from Figure 2 that the flow generally exhibited a linear increase with the addition of LBPA, the same as the trend exhibited at the unmodified hot mix asphalt. The flow value for the modified and unmodified hot mix asphalt between 4% and 5.5% bitumen content met the requirement for FMWH (2016) which states that the flow value for a hot mix wearing course should range between 2mm to 4m. These results are in agreement with the work of [35].

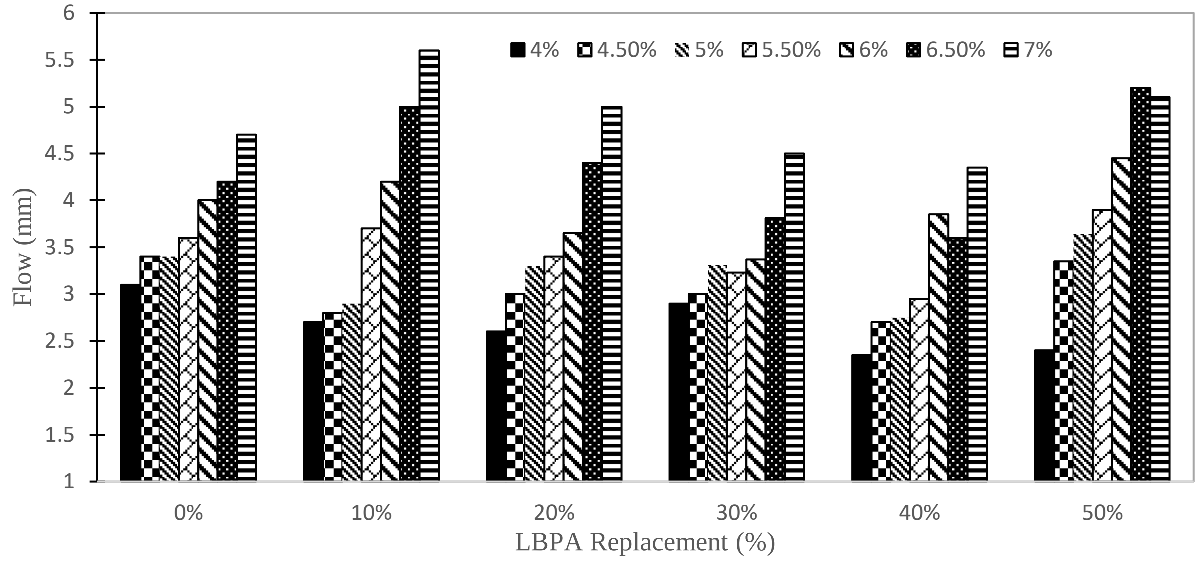

Figure 3 Variation of flow with bitumen content and LBPA

3.3.3. Effect of LBPA on unit weight

The variation in unit weight value with bitumen content and LBPA is shown in Figure 4. It could be observed from Figure 4 that the unit weight exhibited an elastic behaviour at each replacement. That is, as the bitumen content increased, there was a corresponding increase in unit weight, which then decreased with further addition of bitumen. This behavior of unit weight can be attributed to the different specific gravities of materials in the mix. The highest value of 2.28 g/cm^3 was recorded at 20% replacement with 5.5% bitumen content and lowest value of 2.23 g/cm^3 was recorded at various replacements with various bitumen content. A similar trend of results was also observed by [32].

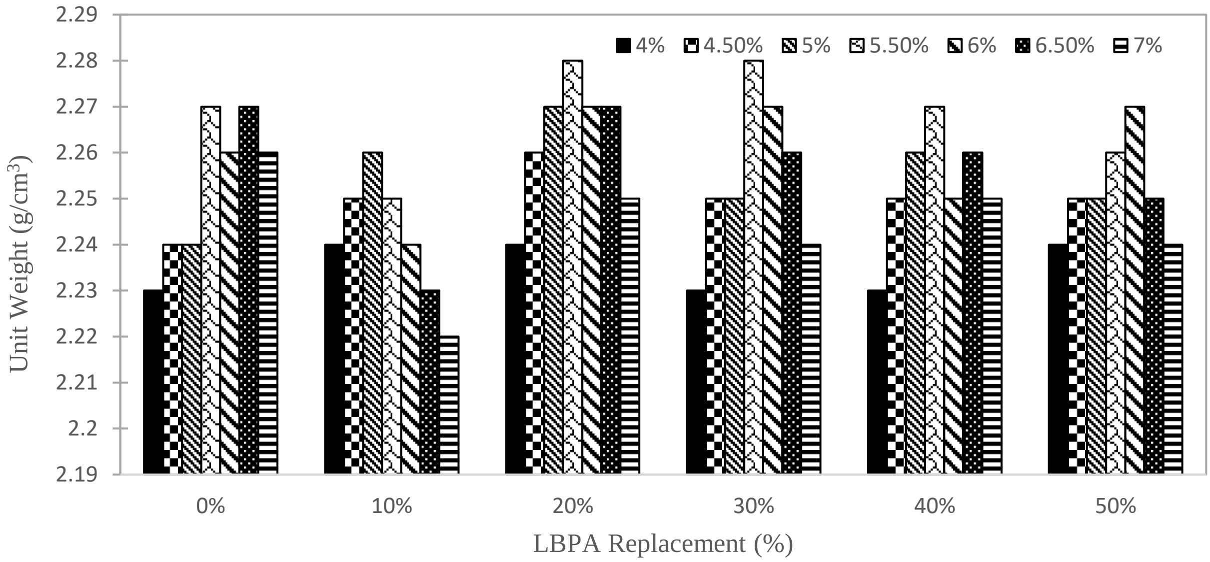

Figure 4 Variation of unit weight with bitumen content and LBPA

3.3.4. Effect of LBPA on VMA

The variation in voids in mineral aggregate (VMA) value with bitumen content and LBPA is shown in Figure 5. It could be observed from Figure 5 that VMA increased with an increase in bitumen content at each replacement. This trend of result is an indicator that the asphalt mixture has been saturated with bitumen and might result in plastic deformation of the mixture [36]. This result is in agreement with the finding of [27].

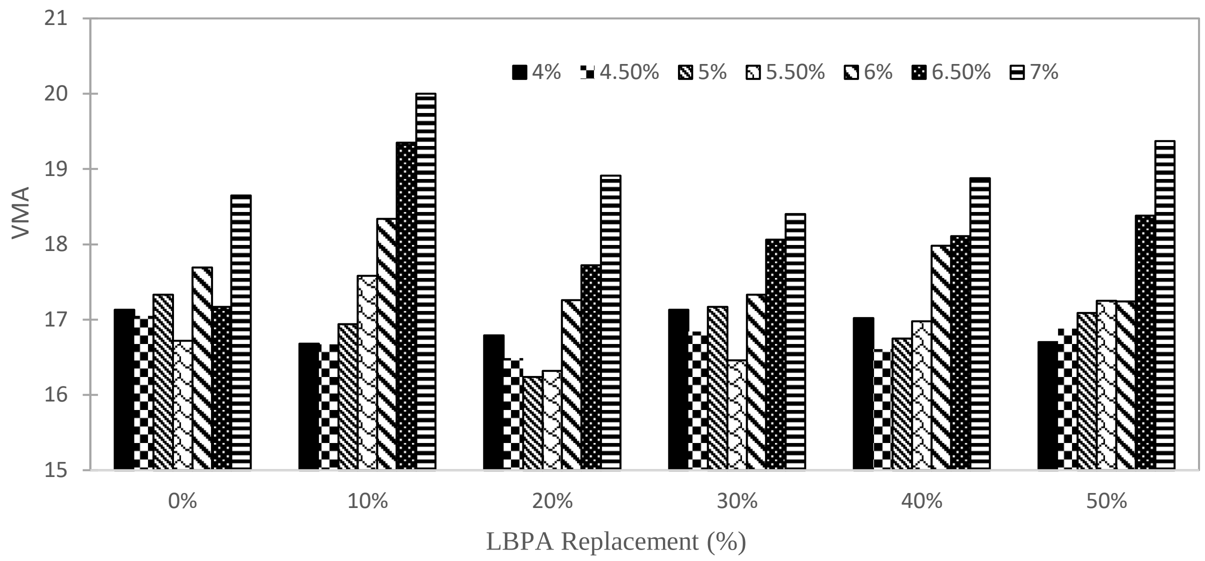

Figure 5 Variation of VMA with bitumen content and LBPA

3.3.5. Effect of LBPA on VFB

The variation in voids filled with bitumen (VFB) value and LBPA is shown in Figure 6. It could be observed from Figure 6 that as the LBPA content increased, there was an increase in VFB values. The increase could be attributed to the adhesive chemical reaction between the LBPA and bitumen. The values of VFB from bitumen content of 5.5-7% at various replacements satisfied the FMWH, (20I6) of 75%-82% for use as a wearing course. A similar result was reported by [34].

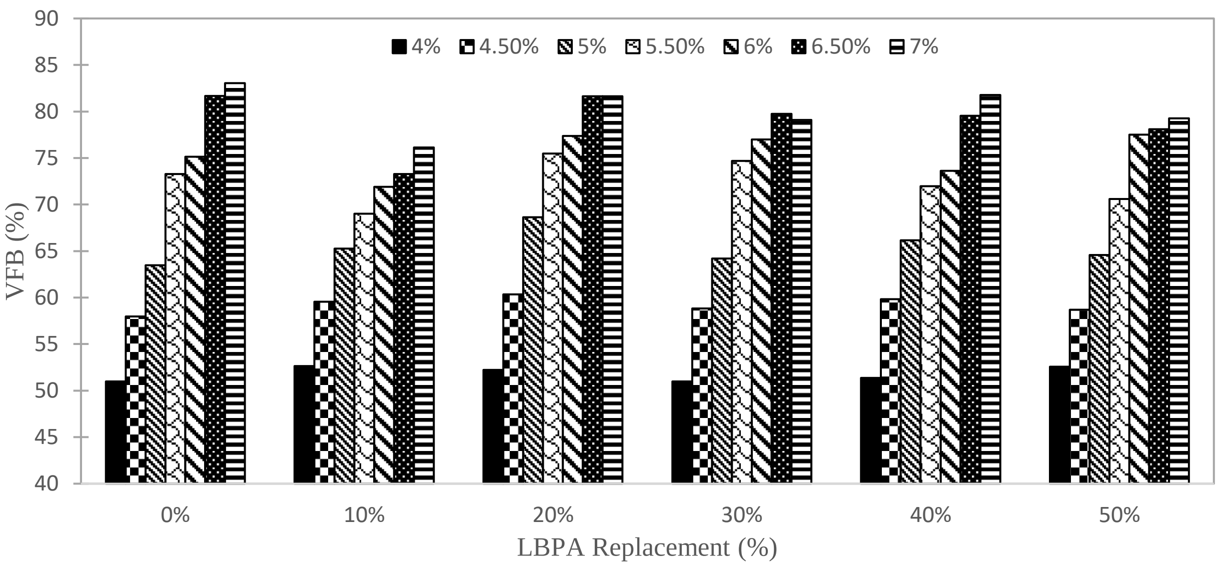

Figure 6 Variation of VFB with bitumen content and LBPA.

3.3.6. Effect of LBPA on Pa

The variation in percent air void in the compacted mixture (Pa) value and LBPA is shown in Figure 7. It could be observed from Figure 7 that there was a decrease in value of the Pa value with the addition of LBPA as compared to the control sample. This decrease could be attributed to the fines or particle size distribution, texture and to a great extent the uniform dispersion of LBPA in the mixture which impacted the asphalt absorption. This decrease also accounts for the increase in stability with increase in LBPA. It should be noted that a percent void at 40% replacement, corresponding to a bitumen content of 5% satisfies the [26] void content between 3% and 5% for use on a wearing surface.

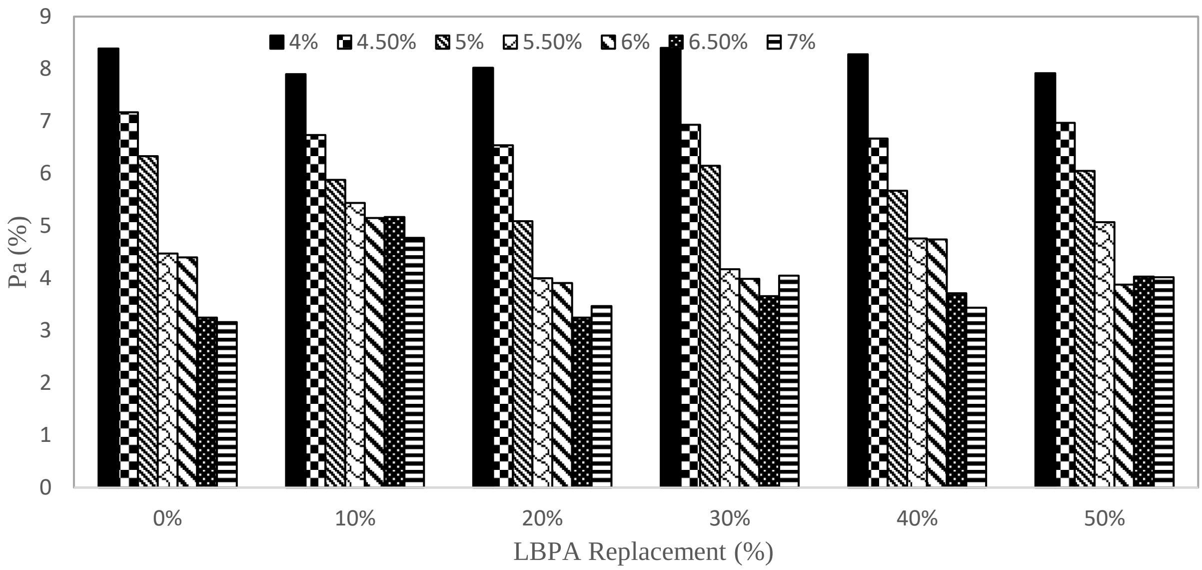

Figure 7 Variation of Pa with bitumen content and LBPA.

3.4. Microanalysis of Hot Mix Asphalt Sample

A micrograph of an unmodified hot mix asphalt sample at 1000x magnification and 250µm magnification scale is displayed in Figure 8. The micrograph depicts a rough texture and surface particle arrangement. The micrograph of the hot mix asphalt also shows the matrix formation of the mixture and the gelling of bitumen over aggregate. The micrograph also shows the flocculation of granite dust particles and the interlock between aggregate particles. This type of aggregate-mineral filler matrix might be related to the lower Marshall stability values that were obtained in the unmodified hot mix asphalt samples. However, the Marshall stability values of the unmodified samples adequately meet [26] criteria of ≥ 3.5kN.

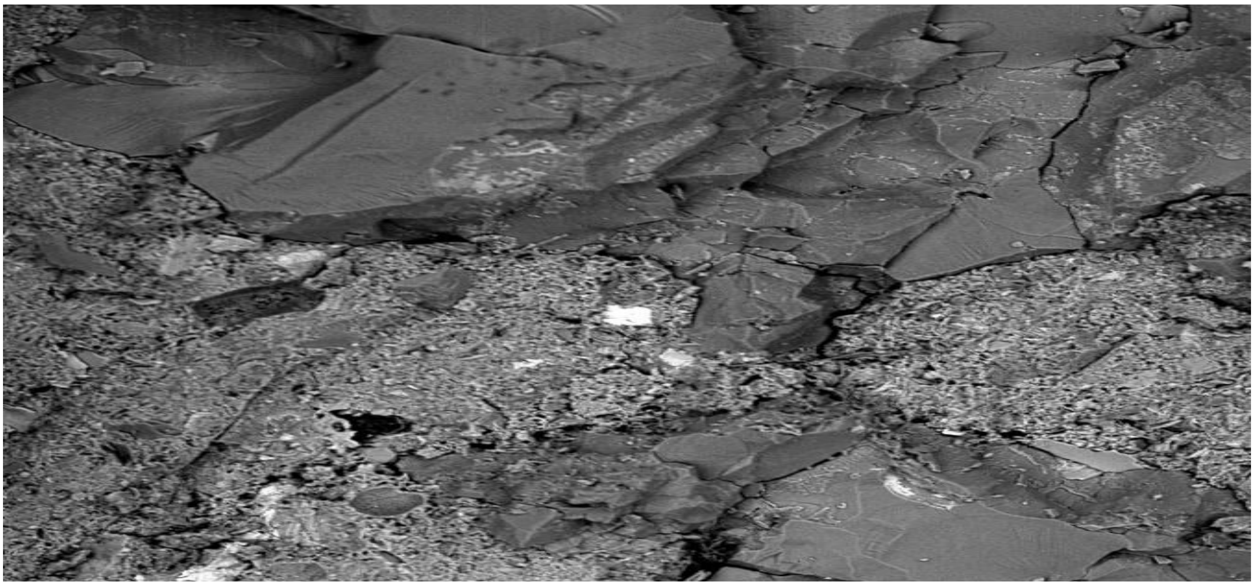

Figure 8 Micrograph of unmodified hot mix asphalt sample at 1000X magnification and 250µm magnification scale.

A micrograph of the modified hot mix asphalt sample (40% LBPA and 5% bitumen content) at 1000x magnification and 250µm magnification scale is presented in Figure 9. The micrograph shows a better filler-aggregate particle arrangement in comparison with the unmodified samples, which were denser and more compact as a result of the coagulation of LBPA particles or the chemical interaction between bitumen and LBPA fine particles, which caused the LBPA to fill up almost all the voids in the mixture. This type of aggregate-mineral filler matrix is related to the Marshall stability values which improved by 17% at 40% LBPA content. The micrograph also shows a rough texture on the surface.

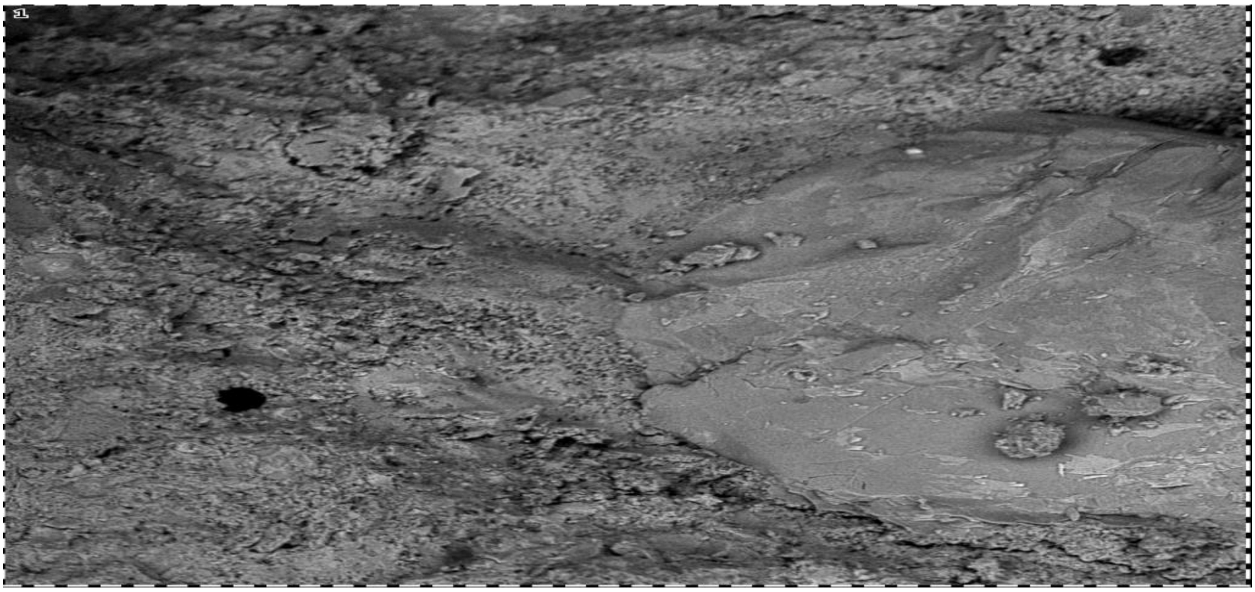

Figure 9 Micrograph of modified hot mix asphalt sample (40% LBPA and 5% bitumen with content) at 1000X magnification and 250µm magnification scale.

4.0 CONCLUSION

The chemical composition of the LBPA satisfies the requirement of ASTM C168-19 and can be grouped as class C pozzolan as it contains (SiO_2) + (Al_2O_3) + (Fe_2O_3) $\geq$ 70%, making it a good mineral filler for hot mix asphalt and as such, it is suitable for use as a mineral filler in hot mix asphalt. The physical properties of aggregate and bitumen used in this research were satisfactory within the limits specified by the Federal Ministry of Works and Housing (2016) and can be used in the production of hot mix asphalt. The Marshall properties of the hot mix asphalt meet the minimum criteria of the Federal Ministry of Works and Housing (2016), which states that the Marshall stability of a hot mix asphalt used for wearing courses should not be less than 3.5 kN. The unmodified and modified mix prepared with granite or LBPA met this requirement. Microstructural analysis of the hot mix asphalt using Scanning Electron Microscopy (SEM) showed improved aggregate-filler particle arrangements for the modified hot mix asphalt in comparison with the unmodified hot mix asphalt, which is unconnected to the improved Marshall properties recorded.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgement

The authors wish to acknowledge the contributions of staffs (academic and nonacademic) of Civil Engineering Department, Ahmadu Bello University, Zaria.

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