Sustainability Assessment of the Engineering Properties of Asphalt Concrete Incorporating Pulverized Snail Shell Ash as Partial Replacement for Filler

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Abstract: In furtherance to the search for reliable and cost-effective road construction materials which is expected to engender the development of sustainable and less expensive pavements, coupled with the increase in agricultural wastes due to the current rise in the consumption of white meat, this research investigated the engineering properties of modified bitumen and subsequent performance of asphaltic concrete incorporating Pulverized Snail Shell Ash (PSSA) as strength modifier and filler. In order to achieve specific objectives, preliminary physical and chemical tests were initialized to characterize the virgin bitumen and snail shell ash. Pulverized proportions of the snail shell ash were blended with bitumen at 10 %, 20 %, 30 %, 40 % and 50 % respectively by weight of mineral aggregates; and subsequently incorporated as filler at the same proportions. The rotational viscometer and penetrometer were engaged to determine the viscosity and penetration of the modified bitumen, and the Marshall mix design method was used to determine the mechanical and rheological characteristics of the resultant asphaltic concrete composites. The modification of bitumen with snail shell ash resulted in a decrease in penetration of virgin bitumen from 80/100 pen to 60/70 pen, including the rotational viscosity. Different mixtures of PSSA at the aforementioned proportions, were evaluated by the design method according to Marshall. The stability was found to be higher than the control mix at 30% of grade which satisfied the Marshall specification for wearing course mixes. X-ray fluorescence (XRF) showed the presence of Oxygen and Calcium in the Hot Mix Asphalt (HMA) modified with PSSA, while the scanning electron microscope (SEM) showed a good blend of the aggregates. The results suggest feasible use of PSSA as partial aggregate substitution in HMA. It was noted that the PSSA was finer than the conventional mineral filler and it filled the voids, engendered a stiffer, and denser mix, as well as reduced the number of voids present in the mix and increased its stability. Experimental results indicated higher stability value of 35.08 KN for the mixture having 30% PSSA as optimum filler content in comparison with conventional mix which was 34.7 kN and standard specification of 34 kN minimum. This study has therefore established the feasibility of using PSSA as alternative filler instead of the conventional in asphalt concrete mix by satisfying the standard specification. Also making the reuse of agricultural waste possible, thereby making construction cost cheaper, and also reducing waste.
1. Introduction

The asphalt pavement industry is committed to innovation in pavement construction as well as focused on its sustainability [1]. Mixing aggregates with asphalt binder and applying heat and pressure to produce asphaltic concrete has been a familiar method for creating long-lasting pavements since the 1800s [2] and since the evolution of the automobile in the early 1900s the asphalt pavement industry continued to make investments in research and engineering targeted at producing stronger asphalt pavements [3] as well as making them more economical and sustainable. Asphalt concrete commonly called asphalt, is a composite material commonly used to surface roads, parking lots, airports [4]. It consists of mineral aggregate bound together with asphalt, laid in layers, and compacted. The terms asphalt concrete, bituminous asphalt concrete, and bituminous mixture are typically used only in engineering and construction documents, which define concrete as any composite material composed of mineral aggregate adhered with a binder [5]. Some efforts focus on specialty mixes, such as porous asphalt or stone-matrix asphalt, for specific applications, others focus more broadly on best practices, enhanced durability, and increased use of recycled materials [6]. The recycled materials are drawn from different sources such as industrial, construction and agricultural wastes. They are normally used as partial or complete substitutes for coarse, fine and filler aggregates in conventional bituminous mixes. However, the focus of this research is on filler substitutes.

The mineral filler in pavements mixtures comprises of very fine particles naturally present in it[7], and usually pass US Standard Sieve No. 200. In this sense, mineral fillers comprise constituents of the pavement skeleton [8]. They make contacts with themselves and the particles of other constituent aggregates and as well serve the purpose of resisting shearing loads on the pavement [9] as well as stiffen the mix. The continuous development of industries over the years coupled with increase in population size in various regions of the world has resulted to the increase in waste materials generation. This therefore has led to the curiosity on how to utilize the waste products produced daily into effective use, and thereby reducing the cost in construction of flexible pavements [10]. The aforementioned agricultural wastes have been the focus of research for some time as substitute for conventional fillers in bituminous mixes [7]. A major approach towards managing them has been to consider the possibility of recycling them as filler substitute [11], which will in-turn reduce their quanta and reduce environmental pollution. The suitability of some alternative materials as fillers in bituminous concrete have been investigated. For example, materials such as waste plastics [12], polymers [13], rice husk ash [14], brake pad [15], steel slag [16], date seed ash [17], carbon powder [18], coal gangue [19], fly ash [20], periwinkle shells [21], recycled brick powder [22], oil shale [23], cow-bone ash [6] and milled egg shells [24] have been investigated in cement and asphaltic concrete composites. Although snail shell ash has been used for the stabilization of expansive lateritic soils for pavement foundation, research has not been found in literature on its utilization as substitute for filler in asphalt. This study therefore assesses the effects of pulverized snail shell ash as filler substitute on the engineering properties of asphaltic concrete.

2. Research Materials and Method Employed

2.1 Materials

Mineral Aggregates

Aggregates where gotten from an on-going construction site in Landmark University, Omu Aran, Nigeria. Coarse aggregates (granite chippings) with sizes larger than 2.36 mm were used, while aggregates whose particle sizes were less than 2.36 mm were adopted for fine aggregates (river bed sand) for the preparation of the control and modified samples. Prior to the laboratory experiments and tests, they were washed and subsequently dried.

2.1.1 Bitumen

Bitumen is a viscoelastic material refined from the fractional distillation of crude oil. It is the binder in pavement mixes with very strong adhesive properties widely used for construction purposes globally
Bitumen 60/70 Grade [25] was used in the production the samples to be tested, both the snail shell modified and control. It was sourced from Civil Engineering Department of Landmark University, Omu-Aran, Nigeria.

2.1.2 Fillers
Sieved particles of the ashed snail shells passing the number 200 mesh were utilized in this investigation. Likewise, particles of conventional mineral filler (quarry dust), retained on sieve number 200 and retained on the pan were used. The snail shell wastes were sourced from the layers pen of Landmark University commercial farms, Omu Aran, Nigeria. They were washed and dried and thereafter pulverized to powder [6].

![Snail Shell Ash](image)

Figure 1: Snail Shell Ash

2.2 Method
In order to determine the appropriateness of materials sourced for this research, they were subjected to various tests in the laboratory. The suitability of these materials in terms of expected desirable properties to produce the control samples, and in accordance with the standard was verified by the tests.

2.2.1 Tests on Mineral Aggregates
Physical tests such as specific gravity (ASTM C127), voids percentage (ASTM C128-15), test for water retention (ASTM D570), test on Abrasion (ASTM C131), bulk density test (ASTM C 127 - 128), flakiness index test (ASTM D4791), aggregate impact test (ASTM D5874 – 16), test on elongation (D4791-19) and moisture content (ASTM D1864) tests were carried out on materials.

2.2.2 Water/Moisture Content Test
Empty cans were branded and their weights were determined. Representative wet soil samples were placed in the can, weighed transferred into the oven at 105°C for 20 to 24 hours. The water content test was determined in accordance with ASTM D1864.

2.3 Tests on Bitumen
2.3.1 Ductility test
According to the American Society for Testing and Materials (ASTM D113)[26] ductility test on bitumen was carried out at 5 cm/min and 25 °C standard condition. Besides, another major prompting for this test was to assess the adhesive capabilities of the asphalt whether good or poor to help predict performance in service.

2.3.2 Flash and Fire Point Test:
Using the Pensky-Martens Closed Tester method (ASTM D93), the flash and fire point tests were carried out. The require temperature at which it would be safe to heat the specimens was determined.

2.4 Blending of aggregates
For the purpose of achieving a mix that would meet the requirements for gradation of bituminous mixtures, coupled with aid of a trial method, an integration of the mineral aggregates was done. Calculation of the
various aggregate size percentages was carried out and benchmarked with the expected requirement. Repeated trials were done until the proportions were within acceptable limits.

2.5 Marshall Properties Test
Marshall properties test was carried out according to (ASTM D 1559-89) [27], on the eight samples produced, each weighing 1200g. The Marshall Properties tested are stability, flow, density, air voids, voids in total mix, and voids filled with bitumen [6]. The results are shown in Table 6.

2.6 Optimum Bitumen Content (OBC)
To determine the OBC, mean values of three of bitumen contents at the highest values of stability and bulk density, and the bitumen content corresponding to the median value of air voids [28], were determined. The three values were determined through Marshall plots.

\[
\text{Optimum Bitumen Content} = \frac{\text{Stability} + \text{Bulk Density} + \text{Air Voids}}{3}
\]  

(1)

Volumetric properties for asphalt mixes usually obtained from OBC such as (i) Voids in Mixed Aggregates (VMA), (ii) Voids Filled with Bitumen (VFB), (iii) stability, (iv) flow, (v) Volume of voids (Vv) and (vi) bulk density were determined as shown in Table 1 and varied with the design requirements of medium traversed roads.

**Table 1. Standard Requirements for Asphalt Wearing Courses**

| Properties  | Type of Mix | Indicators |
|-------------|-------------|------------|
| Air voids (%) | DG | 3 - 5 |
| Surface Course | DG | 75 - 85 |
| VFB (%) | DG | Not less than 7.5 |
| Surface Course | DG | 8 - 17 |
| STABILITY (KN) | DG | 5.0 – 8.0 |
| Surface Course | DG | |

Source: (AASHTO T245); DG = Dense Graded

2.7 Production of the PSSA Samples
Eight Pulverized Snail Shell Ash modified samples were produced vis-à-vis the optimum bitumen content. The mix proportions are 2.5 %, 5 %, 7.5 %, 10 %, 20 %, 30 %, 40 % and 50 %. Sequel to the whole process, they samples were compacted according to (ASTM D1559-89) [30]
3. Results and Discussion

Control sample test results, and of the samples partially modified are as presented below. Others such as Marshall stability test, SEM and XRF are also presented. All tests except SEM and XRF were conducted at Landmark University. The SEM test was carried out at the college of agriculture, University of Ibadan, Oyo State while X-RAY Florescence test and analysis of materials was conducted at the Engineering Materials Development Institute (EMDI), km 4, Ondo road, Akure, Ondo State, Nigeria.

3.1 Combined Sieve Analysis Curves

The distribution of the various aggregate sizes was determined according to American Association of State and Highway Transportation Officials standard (AASHTO T 27). The combined graph of sieve analysis for the mineral aggregates and calcite powder used in the preparation of the asphalt is as shown in Figure 3.

![Combined Particle Size Distribution Curves](image)

**Figure 3: Combined Particle Size Distribution Curves (PDSCs) for coarse, fine, mineral filler aggregates and PSSA**

From the combined particle size distribution graph of the aggregates above, the values corresponding to $D_{10}$, $D_{30}$ and $D_{60}$ on the fine aggregate curve in orange are 0.33, 0.55 and 0.97 respectively, hence the calculated values of $C_u$ and $C_c$ are 2.94 and 1.001 respectively. From ASTMD-2487 soil classification, it can be said that the fine aggregate soil is a fairly graded soil sample because $C_u < 6$. Similarly, the values corresponding to $D_{10}$, $D_{30}$ and $D_{60}$ on the coarse aggregate curve in blue are 0.12, 0.31 and 0.86 respectively. The value of $C_u$ and $C_c$ obtained are 7.17 and 1.005 respectively. According to ASTM D-2487 soil classification, the particles of the coarse aggregates are well graded as $1 \leq C_c \leq 3$. The test results are shown in Table 2.
Table 2: Mechanical Test Results on Coarse Aggregates

| Test carried out                  | Obtained Test Results | Standard Test Values |
|-----------------------------------|-----------------------|----------------------|
| Elongation Index                  | 29.63                 | 30% max              |
| Flakiness Index                   | 28.72                 | 30% max              |
| Density                           | 1500.20kg/m³          |                      |
| Aggregate Crushing Test           | 42.40%                | 45% max              |
| Specific Gravity                  | 3                     | 3                    |
| Aggregate Impact Test             | 19.20%                | 30% max              |
| Los Angeles Abrasion Test         | 48.92                 | 60% max              |

Source: ASTM D2419 – for Aggregates’ Soundness

3.2 Tests on Bitumen

Table 3 shows the results of tests carried out to characterize the bitumen used for this research

Table 3: Standard Engineering Test Results on Bitumen

| Parameters Tested                  | Test Values | Expected Standard Values (in ranges if possible) | Standard |
|-----------------------------------|-------------|---------------------------------------------------|----------|
| Penetration (mm)                  | 71          | 60-70 IS Standard                                 | ASTM D-5 |
| Softening (C)                     | 56          | 45-60 IS Standard                                 | ASTM D-36|
| Ductility (cm)                    | 81          | 75 Minimum IS Standard                            | ASTM D-113|
| Viscosity (secs)                  | 75          | Nil                                               | ASTM D3381|
| Flash Point (C)                   | 274.6       | 175 Minimum BIS                                   | ASTM D-92|
| Fire Point (C)                    | 305.8       | Nil                                               | ASTM D-92|
| Specific gravity                  | 0.98        | 0.97-1.02                                         | ASTM D-70|
| Loss on heating                   | 0.89        | 1.00% max                                         | ASTM D-6 |
| Moisture Content                  | 0.0024      | Nil                                               | ASTM D-41|

3.2.1 Control

Table 4 shows the result from the carried-out marshal test on the control sample. It also shows the uncorrected and corrected Marshall stability. Other parameters shown are Bitumen Content (BC), Specific Density (Gt), Bulk Density (Gm) and Correction Factor (Cf).

Table 4. Results of Marshall Properties Tests

| Test No | % BC | Weight in air | Weight in Water | Gt  | Gm  | % Vol of void (Vv) | % Vol of bitumen (Vb) | Vma (%) | Vfb | Uncorrected stability (kN) | Cf  | Corrected stability (kn) | Flow (mm) |
|---------|------|---------------|-----------------|-----|-----|-------------------|-----------------------|---------|-----|---------------------------|------|--------------------------|-----------|
| 1       | 5.5  | 1017          | 578             | 2.404 | 2.317 | 3.619             | 13.274               | 16.893  | 78.577 | 37.7                     | 1.000 | 37.7                     | 12        |
| 2       | 5    | 1025          | 579             | 2.425 | 2.298 | 5.237             | 11.969               | 17.206  | 69.563 | 37.9                     | 1.000 | 37.9                     | 11.3      |
| 3       | 4.5  | 1002          | 572             | 2.446 | 2.330 | 4.742             | 10.922               | 15.664  | 69.727 | 34                      | 1.000 | 34                      | 10.5      |
| 4       | 4    | 897           | 522             | 2.467 | 2.392 | 3.040             | 9.967                | 13.007  | 76.628 | 35                       | 1.000 | 35                       | 9.6       |
| 5       | 3.5  | 995           | 570             | 2.489 | 2.341 | 5.946             | 8.535                | 14.481  | 58.939 | 28.9                     | 1.000 | 28.9                     | 10.3      |
3.3 Optimum Bitumen Content (OBC)

It is necessary to obtain the Optimum Bitumen Content (OBC) in order to produced asphalt concrete modifier with an alternative filler material. The OBC was determined based on Marshall mix design and analysis technique which ranges from 4.5% to 6.5% of bitumen by standard. A total of 5 samples were tested representing the control mix in this research. As shown in figure 5, the plots each of density, stability, flow, stiffness, void fill with bitumen and void in total mix against % of bitumen were used to determine the OBC.
3.4 Marshall Properties Results of the PSSA Modification as filler
The Marshall properties of the snail shell ash modified asphalt mixture were compared with the control mix and checked with standard expectations for sustainable highway construction purposes. From the modified samples, and the optimum bitumen content obtained, the Marshall experiment was conducted and the resulting parameters of the asphalt concrete mix with snail shell and without snail shell were compared. The required Marshall parameters of the snail shell modified mix were same as the control mix. The following are the results, whose parameters were utilized to obtain the optimum snail shell content. Table 5 shows the summary of the Marshall properties of the snail shell ash modification.

Table 5: Marshall Properties Results of the PSSA Modification as Filler

| PSSA | Vb  | STABILITY (kN) | FLO W (mm) | Gm | Vv (%) | VM A (%) | VFB (%) | OB C |
|------|-----|----------------|------------|----|--------|----------|---------|------|
| 0%   | 10.9| 34.70          | 10.74      | 34 | 4.52   | 5        | 70.69   | 4.27 |
| 10%  | 9.73| 31.16          | 9.06       | 42 | 3.49   | 13.2     | 77.39   | 3.78 |
| 20%  | 8.9 | 26.7           | 9.84       | 23 | 10.8  | 19.7     | 49.2    | 4.75 |
| 30%  | 9.01| 35.08          | 9.04       | 33 | 6.86  | 15.9     | 57.6    | 4.43 |
| 40%  | 9.22| 31.06          | 9.76       | 43 | 2.76  | 11.9     | 80.05   | 3.83 |
| 50%  | 9.02| 23.00          | 11.14      | 42 | 3.21  | 12.2     | 74.7    | 3.65 |
3.5 Summary of Scanning Electron Microscopy (SEM) X-Ray Fluorescence (XRF) Test Results on the Snail Shell Ash Modified Mix

3.5.1 SEM Analysis Test Results

Figure 5 shows the SEM micrograph of the control and snail shell modified samples using SEM machine at different magnifications. The modified samples micrographs show proper interaction between the particles of the conventional aggregates and the pulverized snail shell ash.

Figure 5: SEM Micrographs of the Control and Snail shell Modified Samples at (a) 5000x mag, (b) 4000x mag, (c) 5000x mag, and (d) 6000x mag.

From the above SEM results shown, it can be observed that the voids in the control tends to be more than that in the modified sample which implies that the Pulverized Snail Shell Ash (PSSA) was able to penetrate into more voids, thereby increasing the stability and stiffness of the asphaltic concrete. As seen in figure 7, it can be observed that Oxygen is the most abundant element containing 71.17% by weight, and Calcium which is next having a weight percentage of 26.53% in the whole composition and lastly carbon which isn’t in abundance but can be seen to be present having 2.3%. The chemical composition of this
material enables it to bond well with the bitumen there by making it possible to be used as a partial substitute for filler in asphaltic concrete.

3.5.2 XRF Test Results
Table 6 shows the level and intensity of elements present in PSSA. It can be observed that the pulverized snail shell ash is filled with high intensity of Calcium, which is responsible for the pozzolanic characteristic of the material. The following results were gotten from the XRF carried out on PSSA.

| Sample Name | SNAIL SHELL (g) | Test Time(s) | Suppliers | Work Curve | Voltage (KV) | Operator | Date       |
|-------------|-----------------|--------------|-----------|------------|--------------|----------|------------|
| Suppliers   | Work Curve      | ORE          | 40.0      | 001        | 350          | 18/03/2019|
| Element     | Intensity       | Content      | Mg        | 0.0000     | 0.0000       |          |            |
|             |                 |              | Al        | 0.0011     | 0.3253       |          |            |
|             |                 |              | Si        | 0.0066     | 0.5769       |          |            |
|             |                 |              | P         | 0.0071     | 0.3331       |          |            |
|             |                 |              | S         | 0.0084     | 0.6389       |          |            |
|             |                 |              | Ca        | 0.7465     | 73.3197      |          |            |
|             |                 |              | Ti        | 0.0000     | 0.0000       |          |            |
|             |                 |              | V         | 0.0000     | 0.0014       |          |            |
|             |                 |              | Cr        | 0.0000     | 0.0000       |          |            |
|             |                 |              | Mn        | 0.0000     | 0.0000       |          |            |
|             |                 |              | Co        | 0.0001     | 0.0000       |          |            |
|             |                 |              | Fe        | 0.0013     | 0.2079       |          |            |
|             |                 |              | Ni        | 0.0003     | 0.0133       |          |            |
|             |                 |              | Cu        | 0.0006     | 0.0117       |          |            |
|             |                 |              | Zn        | 0.0007     | 0.0223       |          |            |
|             |                 |              | As        | 0.0001     | 0.0000       |          |            |
|             |                 |              | Pb        | 0.0001     | 0.0000       |          |            |
|             |                 |              | W         | 0.0001     | 0.0000       |          |            |
|             |                 |              | Au        | 0.0000     | 0.0000       |          |            |
|             |                 |              | Ag        | 0.0000     | 0.0000       |          |            |
|             |                 |              | Rb        | 0.0000     | 0.0000       |          |            |
|             |                 |              | Nb        | 0.0001     | 0.0000       |          |            |
|             |                 |              | Mo        | 0.0016     | 0.2060       |          |            |
|             |                 |              | Cd        | 0          | 0.0000       |          |            |
|             |                 |              | Sn        | 0.002      | 0.3571       |          |            |
|             |                 |              | Sb        | 0.0027     | 0.3339       |          |            |

4. Conclusion and Recommendation
This research has made it possible to confidently utilize agricultural wastes (snail shell) as partial replacement for filler in asphalt and achieve reasonable physical properties. From the result obtained for
different PSSA modification proportions of 10 %, 20 %, 30 %, 40 %, 50 % for partial replacement of the filler of particle size 0.075 mm, it was found suitable for the construction of low volume pavements at 20 % and 30 %. It was also observed that the Marshall stability values obtained when the milled snail shell ash was added at 20 % and 30% respectively were higher than the control value. Furthermore, the XRF, EDS, SEM, stability and the flow results obtained from the experimental work showed that the physical and chemical properties of the asphaltic concrete had a significant improvement on them. Based on these findings, it is therefore recommended that 30 % PSSA asphaltic concrete be applied on medium traffic roadways. This will in turn engender reduction in the quantity of the agricultural waste, as well as reduce the quantity of conventional materials used for construction, hence minimizing pavement construction costs.

Authors’ Contributions
Author 1,5*, conceived the theory, formulated the methodology, sourced and presented the data, prepared and edited the manuscript. The laboratory experiments were conducted by Author O. J. Aladegboye. Results were discussed and commented on by all the authors. Author 1,5*, handled all correspondences, submission, review processes and zoom presentation.

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