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Contributions of Periwinkle Shell Ash on the Stability and Elastic Properties of Modified Asphalt Concrete for a High Trafficked Road

Amadi-Oparaeli, Kemejika Ichechi*, Miefama Oju, Igwe, Aleruchi Enwuso

Department of Civil Engineering, Rivers State University, Nkpolu Oroworukwo. Port Harcourt, Rivers State, Nigeria.

Corresponding Author:** ***Kemejika Ichechi, *Department of Civil Engineering, Rivers State University of Science and Technology, Port Harcourt, Rivers State, Nigeria*

Abstract: *The adverse environmental impact of industrial and agricultural waste/by-products combined with the rising cost and difficulty in obtaining construction materials have influenced research into better ways to manage these wastes/by-products by incorporating them in asphalt concrete mix design.Different researches have shown that some agricultural waste/by-products can be included as mineral fillers in hot-mix asphalt concrete to obtain certain desirable properties. It is on this basis that this research attempts to investigate the effect of Periwinkle Shell Ash(PSA) on the mechanical and elastic properties of asphalt concrete, which will serve as basis for the use of such materials in pavement construction. An experimental approach was adopted to achieve this goal using the Marshal Mix design method topreparerepresentative samples.Stability and flow were obtained using the Marshal apparatus, while the Asphalt Institute Model was used to obtain the dynamic modulus of the samples for both un-soaked and soaked conditions. The results show that the mechanical properties, such as stability, density, flow, air voids, tensile strength, and tensile and compressive strains obtained from the modified HMA concrete was better than that of the conventional (unmodified) HMA concrete due to the addition of Periwinkle Shell Ash. However, 2.5% PSA content by weight of aggregates is the threshold content to attain maximum values of stability and tensile strength.The Elastic properties such as Dynamic Modulus E* (which relates to the stiffness of the HMA concrete), Elastic modulus, and Poisson's ratio obtained from the modified HMA concrete significantly improved upon addition of PSA. However, while the dynamic modulus increases linearly with increasing PSA content, the filler must not exceed 2.5% by weight of aggregates at in order to achieve maximum elastic modulus.*

Keywords: *Periwinkle Shell Ash, Asphalt Concrete, Compressive Strain, Dynamic Modulus, Tensile Strength*

1. INTRODUCTION

Continuous generation of wastes arising from industrial by-products and agricultural residue, create acute environmental problems both in terms of their treatment and disposal. The construction industry has been identified as one of the areas where the waste can be absorbed, with the majority of such materials identified as fillers useful in concrete (Antiohos *et al.*, 2005). If these fillers have pozzolanic properties, they impart technical advantages to the resulting concrete and also enable larger quantities of cement replacement to be achieved (Hossain, 2003). Appropriate utilization of these materials brings ecological and economic benefits sincerecycling waste materials into useful products has becomeone of the most proactive and efficientmethods of solving waste disposal problems (Ahmed, Ayman & Afaf, 2006). Recycling is a process of changing waste materials into new products to prevent hazards associated withwaste, reduces the consumption of fresh raw materials, and it also reduces greenhouse gas emissions arising from the conventional method of disposing such wastes (Grosse, 2010). Many researchers have been conducted to determine ways of improving the properties of asphalt concrete to meet the ever changing conditions of loading, environment, as well as cost of construction. Studies have been conducted to determine the effects of different types of mineral fillers on asphalt concrete mix properties. For example, Cabeza *et al*. (2010) suggest that mineral fillers (e.g. cement dust, quarry dust, fly ash, etc.) are unique in their ability to allow porous materials to become stronger by filling the pores and voids on the surface of such materials.

Huang, Bird, & Heidrich (2007) and Al-Saffar (2013), have conducted experiments on the incorporation of several types of mineral filler into asphalt in its mix design; including lime stone powder, waste glass, and quarry dust. Cabeza *et al*. (2010) indicates that there are several other filler materials usable in construction (e.g. ceramic, bricks, Portland cement, fly-ash, lime etc.). Furthermore, there is a wide range of combined materials, which are manufactured by processing different material ls from different origins so as to be able to improve structural performance when in use (Fassi & Maina, 2009). The present study is aimed at investigating experimentally the contributions of Periwinkle Shell Ash as mineral filler in Asphalt Concrete Mixtures, especially the stability characteristics. This is important because of the following reasons: Also this study therefore will enhance their perception of Periwinkle shell ash as mineral filler asphalt in pavement construction, and expose significant quality specifications worthy of consideration in practice.

2. MATERIALS AND METHODS

Sources of the materials used and the various testing procedures which are performed in compliance with standard specifications such as ASTM, British Standards, Indian Standards and AASHTO are described. The procedure for Marshall Mix design is also outlined.

2.1. Sample Collection

The materials used for this research includes fine and coarse aggregates, bitumen, and filler. The fine aggregate used was sharp sand, with specific gravity of 2.66, while the coarse aggregate was all-in graded gravel with specific gravity of 2.78, and having maximum size of a half-inch (12.7mm). These aggregates were obtained from the local building materials market at Mile-3, Diobu, Port Harcourt, Rivers State, Nigeria. Laboratory tests carried out on the aggregates included the following:

Gradation analysis(Sieve Analysis)

2.2. Specific Gravity Test

The binder used was grade 60/70 penetration bitumen as recommended by ASTM D1559 for Highway Pavements. This binder was obtained from Julius Berger Construction Company Port Harcourt, Rivers State, Nigeria. Within the scope of this study, the tests carried out on binder included;

- Specific gravity Test
- Penetration Test
- Viscosity Test
- Softening Point Test.

The filler used was Periwinkle Shell Ash, obtained from the local materials market at Mile-3, Diobu, Port Harcourt, Rivers State, Nigeria. Only Specific Gravity test was carried out on the pozzolan.

2.3. Specific Gravity of Periwinkle Shell Ash

For the mineral filler, the pycnometer method was used to obtain the weight of a given volume of the modifier and also used to obtain the weight of an equal volume of water. Specific gravity was thus obtained by dividing the weight of the modifier by the weight of an equal volume of water.

2.4. Presentation of the Models Used

This section highlights the models used in the determination of the mechanical and elastic properties of the modified and unmodified asphalt concrete in addition to the conventional density-voids analysis. The Stability and flow results were obtained using the Marshall apparatus, which simultaneously displays the loading applied to the samples as well as their displacements via an attached Linear Variable Displacement Transducer (LVDT).

The mechanical and elastic properties were determined using models as prescribed in various textbooks. The Dynamic Modulus was obtained using the Asphalt Institute Model. The Asphalt Institute Model (1993) developed by the Asphalt Institute, gives a method for design in which the dynamic modulus is determined, as presented in Huang's Pavement Analysis and Design textbook (1993). The model is given below;

$E^* = 100{,}000\,(10^{\beta_1})$ 3.11

$$\beta_1 = \beta_3 + 0.000005\beta_2 - 0.00189\beta_2 f^{-1.1} \quad 3.12$$

$$\beta_2 = \beta_4^{\,0.5} T^{\beta_5} \quad \text{Eqn.3.13}$$

$$\beta_3 = 0.553833 + 0.028829\left(P_{200} f^{-0.1703}\right) - 0.03476V_a + 0.07037\lambda + 0.931757 f^{-0.02774} \quad 3.14$$

$$\beta_4 = 0.483V_b \quad 3.15$$

$$\beta_5 = 1.3 + 0.49825\log f \quad 3.16$$

$\lambda = 29{,}508.2\,(P_{77°F})^{-2.1939}$ 3.17

Where,

|E*| = asphalt mix complex modulus, in psi;

λ = bitumen viscosity, in 10^6 poise;

f = load frequency, in Hz;

V_a = percent air voids in the mix, by volume;

V_b = percent bitumen content, by volume;

T = Temperature (^{0}F)

$P_{77°F}$ = penetration at 77°F or 25°C

P_{200} = percent passing No. 200 sieve, by total aggregate weight

The model for Elastic modulus, tensile and compressive strength, and Poisson's ratio are given in the equations below:

$$E = \frac{1}{\varepsilon x}(\sigma x - \mu\sigma y) \quad 3.18$$

$$\sigma x = \frac{2P}{\pi t d} \quad 3.19$$

$$\sigma y = \frac{-6P}{\pi t d} \quad 3.20$$

$$\mu = \frac{\varepsilon x}{\varepsilon y} \quad 3.21$$

Where,

E = asphalt mix elastic modulus, in Mpa;εx = tensile strain of sample, σx = Tensile stress of sample, σy = Compressive stress of sample, μ = Poisson's ratio of sample, P = Stability of sample

t = Thickness of sample, d = Diameter of sample

These models were programmed into a Microsoft excel worksheet to make its computations more efficient. Gradation of Aggregates, Mix proportion, Results and Graphs of the focused properties versus modifier content were produced and their analysis is given.

2.5. Grading of Aggregates

The gradation analysis procedure involves separating a sample of dry fine or coarse aggregates of known mass through a set of sieves in order to determine the grading (the particle size distribution) of the coarse and fine aggregates as specified by ASTM C136-01 (BS: 410-69). Dry samples of the aggregates were weighed and then placed on the set of sieves stacked in order of increasing sizes. The sieves were then agitated for at least two minutes and the mass retained on each sieve was weighed. The percentage passing percentages were calculated and recorded. The particle size distributions were then obtained graphically by plotting the percentage passing each sieve against the corresponding sieve size.

Figure1. *Aggregate Sieving operation*

Table1. *Gradation of Sand (Sample Size = 1200g)*

Sieve No. (mm)	Mass Retained	Percentage on Sieve	Percentage Retained	Percentage Passing
4.75	4	0.3	0.3	99.7
3.35	10	0.8	1.2	98.8
2.36	24	2.0	3.2	96.8
2.00	14	1.2	4.3	95.7
1.18	90	7.5	11.8	88.2
0.850	121	10.1	21.9	78.1
0.600	442	36.8	58.8	41.3
0.425	232	19.3	78.1	21.9
0.300	127	10.6	88.7	11.3
0.150	129	10.8	99.4	0.6
0.075	4	0.3	99.8	0.3
Pan	1	0.1	99.8	0.2
Sum	1198	99.8		

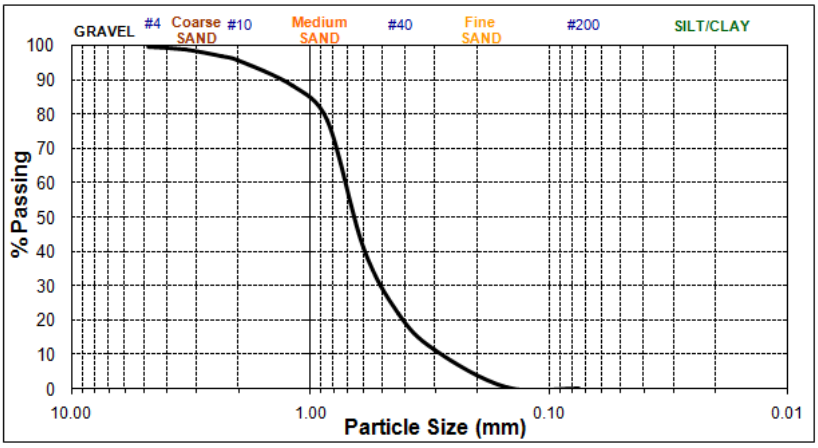

Figure2. *Particle Size distribution for Sand*

Table2. *Gradation of Gravel (Sample Size = 1200g)*

Sieve No. (mm)	Mass Retained	Percentage on Sieve	Percentage Passing
25.4	0	0.0	100.0
19	0	0.0	100.0
13.2	106.5	8.9	91.1
9.5	573.6	47.8	43.3
6.7	317.8	26.5	16.8
4.75	99.1	8.3	8.6
3.35	60.8	5.1	3.5
2.36	5.3	0.4	3.1
1.18	4.8	0.4	2.7
0.425	10.2	0.9	1.8
0.3	0	0.0	1.8
0.075	15	1.3	0.6
Sum	1193.1	99.9	99.4

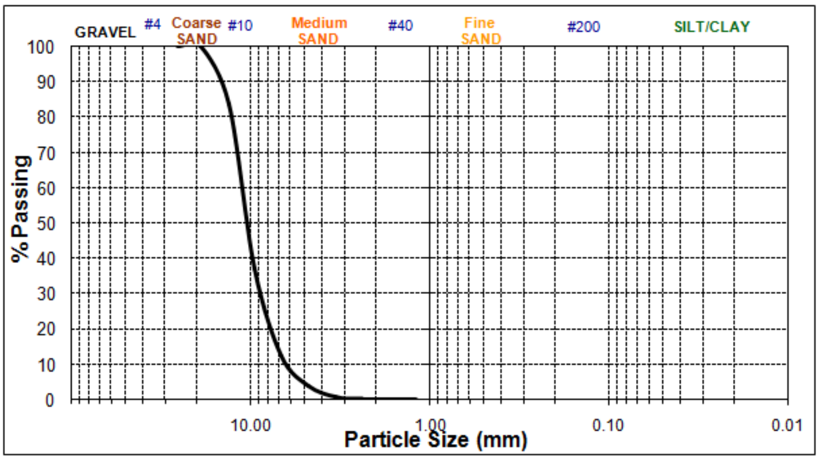

Figure3. *Particle Size distribution for Gravel*

Table3. *Schedule of Mix proportion for Aggregates*

Sieve (in.)	Sieve (mm)	Specification Limit	% passing Aggregate A (Gravel)	% passing Aggregate B (Sand)	Mix Proportion (0.60A+0.40B)	Tolerance
3/4”	19.1	100	100.0	100.0	100.0	±6
½”	12.7	76-92	91.1	100.0	94.7	±6
3/8”	9.52	64-79	43.3	100.0	66.0	±5
No. 4	4.75	40-60	8.6	99.7	45.0	±5
No.10	1.18	23-37	2.7	87.4	36.6	±4
No. 40	0.425	7-20	1.8	21.2	9.6	±4
No. 80	0.300	5-13	1.8	10.6	5.3	±3
No.200	0.075	3-8	0.6	0.3	0.5	±1.5

Table4. *Mix Properties for Unmodified Asphalt Concrete*

Binder %	**G_{mb}**	**Stability (N)**	**Density (kg/m^3)**	**Flow (mm)**	**VTM (%)**	**VMA (%)**
4	2.181	13335	2181	1.745	10.70	17.42
4.5	2.259	17410	2259	2.33	6.42	14.49
5	2.274	24305	2274	2.68	4.68	13.91
5.5	2.290	28852	2290	2.695	2.87	13.29
6	2.194	15767	2194	2.975	5.88	16.94

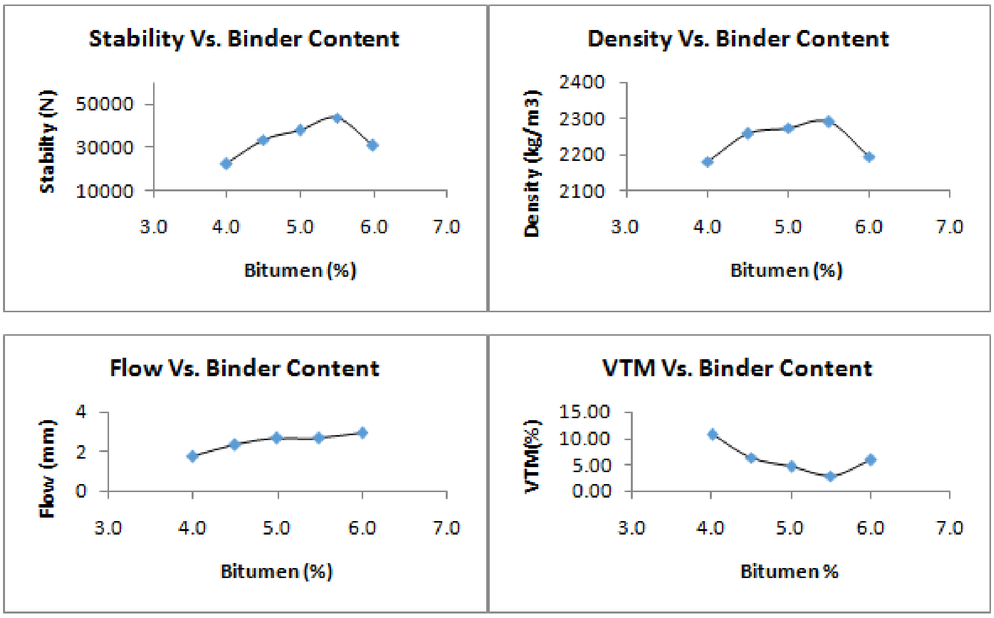

Figure4. *For Optimum Asphalt Content*

Table5. *Variation of Strength Properties of Modified Asphalt Concrete at varying PSA contents*

Periwinkle Shell-Ash (%)	Stability (N)	Elastic Modulus E (N/mm^{2})	Dynamic-Modulus-E* (psi)	Poisson's Ratio (µ)
0	27755	1.001	81984.56	0.586
0.5	28410	1.030	88929.99	0.586
1	31520	1.311	93416.94	0.633
1.5	32310	1.483	102571.17	0.546
2	36090	1.761	109871.27	0.569
2.5	36730	2.026	114815.93	0.525
3	20745	1.448	124822.13	0.488

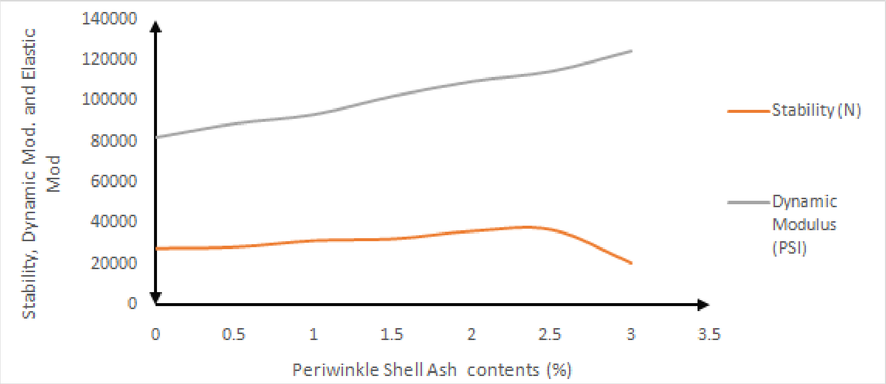

Figure5

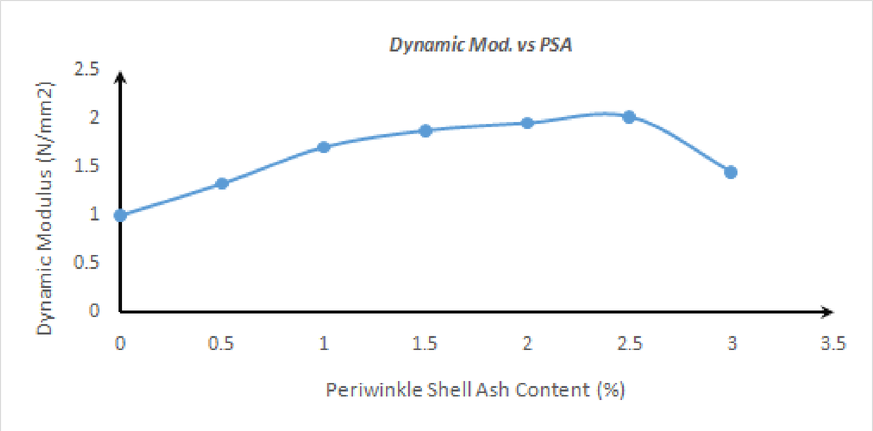

Figure6

3. Results and Discussion

The technical presentation of the results and analysis of the experiments conducted for this research. It concentrates on the changes in the stability and key elastic properties with respect to addition of Periwinkle Shell Ash (PSA). These results are tabulated and graphical representations are provided where necessary. Other parameters of the unmodified asphalt concrete such as stability, density, flow, and air voids were also considered.

3.1. Variation of Stability Property at Varying PSA Content

Figures 5 illustrate the Stability behaviour of the modified mixes with respect to various PSA contents. As illustrated in the above figure, it is seen that for the modified mixes stability increases by 2.4% from 27755N for the unmodified mix to 28410 N upon addition of 0.5% PSA. Addition of 1%, 1.5%, 2% and 2.5% PSA further increased stability by 13.6%, 16.4%, 30% and 32.3% to 31520 N, 32310 N, 36090 N and 36730 N respectively. However, at 3% stability reduced by 25.3% to 20745 N; indicating that further increase in PSA content would cause a corresponding decrease in the stability of the modified asphalt concrete mix. This may be because the load bearing aggregates has been reduced following the in the fine (PSA) contents; and the mixture has become brittle, thus the mix becomes weak to resist axle loads.

3.2. Variation of Elastic Modulus (E) at Varying PSA Content

As illustrated in figure 6, Elastic modulus (E) of the asphalt concrete showed almost identical set of values for the various PSA contents. Elastic modulus increased by 2.9% from 1.001 MPA for the control sample, to 1.030 MPA at 0.5% PSA content. This value further increased by 31.1% to 1.311 MPA at 1% PSA content; by 48.3% to 1.483 MPA at 1.5% PSA content; by 76.1% to 1.761 MPA at 2% PSA content; and peaks by 202.6% to 2.026 MPA at 2.5% PSA content. However, the value of elastic modulus drops to 1.448 MPA at 3% PSA content, indicating that further addition of PSA filler would cause a corresponding decrease in the value of elastic modulus of the mix.

3.3. Variation of Dynamic Modulus (E*) at Varying PSA Content

As illustrated in figure 5 the Dynamic Modulus(E*) at a load frequency of 10Hz increased linearly with increasing PSA content. From Table 5, it is seen that compared with the control mix, the dynamic modulus E* increased by 8.5% from 81984.56PSI for the unmodified mix to 88929.99PSI upon addition of 0.5% PSA. Dynamic modulus further increased by 13.9% to 93416.94 PSI at 1% PSA content; increased by 25.1% to 102571.17 PSI at 1.5% PSA content; increased by 34% to 109871.27 PSI at 2% PSA content; increased by 40% to 114815.93 PSI at 2.5% PSA content; and increased by 52.2% to 124822.13at 3% PSA content. This indicates that increase in PSA content caused a corresponding increase in the stiffness of the modified asphalt concrete mix. This increasing stiffness may be as a result of the increase in bulk density of the mix resulting from the addition of PSA.

4. CONCLUSION

A review of related literature shows that although a lot of research has been conducted with respect to using alternative materials for improving pavement performance, more still needs to be done as pavement performance is subject to the prevailing conditions in different geographical locations.

The conclusions drawn from this research are based on the aim and general finding of the project. While the aim of this research was based on unraveling the effect of Periwinkle Shell Ash on the mechanical and elastic properties of HMA concrete, the results obtained were able to help identify this effect. Thus, the following conclusions have been drawn:

The mechanical properties such as stability, density, flow, air voids, obtained from the modified HMA concrete was better than that of the conventional (unmodified) HMA concrete due to the addition of Periwinkle Shell Ash. However, 2.5% PSA content by weight of aggregates is the threshold content to attain optimum values of stability and tensile strength.

The Elastic properties such as Dynamic Modulus E* (which relates to the stiffness of the HMA concrete), Elastic modulus, and Poisson’s ratio obtained from the modified HMA concrete significantly improved upon addition of PSA. However, PSA content must not exceed 2.5% by weight of binder at optimum in order to achieve maximum elastic modulus.

RECOMMENDATION

Since the analysis of mechanical and elastic properties for the modified HMA concrete showed improved performance of the pavement due to addition of Periwinkle Shell Ash, the following recommendations are provided considering the scope, limitation and general findings:

- Periwinkle Shell Ashcan serve as an excellent material for the modification of HMA concrete for such desirable properties as improved stability, stiffness, durability, and resistance to stripping.

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