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Improving Densibility and Mix Design Properties of Modified Asphalt Concrete for Esal>10^6 using Mineral Fillers

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Abstract: *Gradual disintegrationseen in an asphalt pavementas distresses is most often instigated by failure of the surface due to many factors. Traffic loading, Stripping or raveling is another possible cause of such effects. Stripping occurs when poor adhesion between asphalt cement and aggregate allows the aggregate at the surface to dislodge. As a result, mineral fillers in hot-mix asphalt concrete to obtain certain desirable properties has been practiced and they have improved mix design properties- particularly Density and stability. It is on this basis that this research attempts to show the impact of Fly Ash (FA) and Portland cement (PC) on the Mix Design 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 to prepare representative samples. Stability was obtained using the Marshal apparatus, while the Asphalt Institute Model was used to obtain mix design 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 Fly Ash and Portland cement. However, 3.0% Portland Cement and 1.5% Fly Ash content by weight of aggregates is the threshold content to attain maximum values of stability and Density as part of the Mix Design properties considered; obtained from the modified HMA concrete significantly improved upon addition of PC and FA respectively. However, while the stability increases linearly with increasing PC content, the filler must not exceed 3.0% by weight of aggregates in order to achieve maximum strength and improved density that this study considered.*

Keywords: *Portland Cement, Fly-Ash, Asphalt Concrete, Stability, Density, Modified and Mix Design Properties*

1. INTRODUCTION

Asphalt concrete mixes are used in the surface layer of road and airfield pavements. The mix is composed primarily of aggregates and asphalt cements. Some types of asphalt mixes are also used in base course. The design of asphalt paving mix, as with the design of other engineering materials is largely a matter of selecting and proportioning constituent materials to obtain the desired properties in the finished pavement structure. These materials basically include bitumen, aggregates (fine and coarse), and mineral filler.

The idea of improving the properties of asphalt concrete by addition of various mineral fillers for better performance has been in existence for many years. A lot of studies have been conducted to determine the effects of fillers on asphalt concrete mix properties. The reason for the creation of these composites is due to the need for materials with specific properties for specific applications. For example, mineral fillers (e.g. cement dust, quarry dust, fly ash, etc.) are unique in their ability to allow porous materials to become stronger (Cabeza *et al*. 2010) by filling the pores and voids on the surface of such materials.

Researchers such as Al-Saffar (2013), Huang, Bird, & Heidrich (2007)have reported on the incorporation of several filler types into asphalt in its mix design; including waste glass, lime stone powder, and glass powder. Cabeza *et al*. (2010) indicates that there are several other filler materials usable in construction (e.g. ceramic, bricks, quarry dust, fly-ash, lime etc.). Such materials may be used primarily to pave floors in garages parking lots, sidewalks, playgrounds and parks. These materials are generally classified based on their origin, which can be from plants, synthetics or minerals and based on their structure: fine, fibrous or granular (Papadopoulos, 2005). Furthermore, there is a wide range of combined materials, which are manufactured by processing different materials from different origins so as to be able to improve structural performance when in use (Fassi & Maina, 2009).

The increasingly large loads on highway pavements combined with adverse environmental conditions, such as excessive heat, flooding, and overuse lead to its rapid deterioration and structural failures, such as rutting, shear failure, fatigue cracking etc., causing unnecessary delay in traffic flow, distortion of pavement aesthetics, and most significantly, loss of lives and property (Afolayan & Abidoye 2017). As a result, it is important to develop and adopt technically improved asphalt concrete mixes; either through reappraising the construction materials and methods used in asphalt concrete mixes, or innovating high performance mixes (which is the attempt of this study), to overcome the challenges mentioned above.

However, there is limited data on the effect of ordinary Portland cement on the elastic and mechanical properties of asphalt concrete used on roads especially within the Nigerian terrain, considering the fact that a significant amount of researches conducted have dwelled on conventional stability and flow, and density-voids analysis, little is known about the effects on elastic properties such as elastic and dynamic modulus, and Poisson's ratio; and mechanical properties such as tensile strength, tensile strain, and compressive strains. As a result, it is difficult to adequately quantify the effect that the use of mineral fillers has on mechanical and elastic properties of asphalt concrete pavements.

Various researches have shown improvements in pavement resistance to rutting and fatigue cracking by using several mineral fillers. A recent effort by Shanbara, Ruddock, Atherton &Nassir (2018) showed that the use of ordinary Portland Cement (OPC) produced a substantial improvement in the mechanical properties, moisture damage resistance, as well as lower thermalsensitivityof the Asphalt concrete mixture. In a similar research, Ahmed, Othman, &Mahmoud (2006) concluded that there were significant enhancements in Marshall and mechanical properties ofasphalt concrete mixtures when cement dust was used. Marshall testing results indicated anincrease in the stability, density and a decrease in the flow, voids ratio and voids in mineralaggregates when the percentage of cement dust content increases. The indirect tensile strength andunconfined compressive strength also increased as the ratio of cement dust increased.Thus, if similar results as those found in the literatures regarding modified asphalt pavements in other countries can be expected when used on Nigerian roads, pavement performance could improve and rehabilitation costs reduced.

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 (PC), waste glass, and Fly Ash 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.

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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 Portland cement and Fly Ash, obtained from the local materials market at Mile-3, Diobu, Port Harcourt, and Eleme Petro-Chemical all in Rivers State, Nigeria. Only Specific Gravity test was carried out on the pozzolans.

2.3. Specific Gravity the Pozzolans

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 Mix Design properties (stability and density) of the modified and unmodified asphalt concrete in addition to the conventional density-stability 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

Figure1. *Marshall Samples and Testing*

The results from these tests are then used to carry out the density-stability analysis, after the determination of the other linking properties as presented in this study.

2.5. Determination of Optimum Binder Content (OBC)

Vital to asphalt concrete mix design is the determination of Optimum Binder Content (OBC) because it sets a basis for the comparison whether a particularmix design should be accepted or rejected based on minimum requirements as per design specification. It is on this basis that the OBC was determined. The average values of Bulk Specific Gravity, Stability, Flow, VTM, VMA, and VFB obtained were plotted separately against the binder contents and a smooth curve drawn through the plotted values. The OBC for the HMA mixture was determined by taking the average value of the following three bitumen contents found form the graphs plotted:

- Binder content corresponding to maximum stability(x)
- Binder content corresponding to maximum bulk specific gravity (y)
- Binder content corresponding to the median of designed limits of percent air voids (z)

By applying the formula the stability value, flow value, density and air voids were then checked for suitability with Marshall Mix design specifications.

OBC= 1/3(X+Y+Z).

2.6. Modified HMA Concrete Preparation

The procedure adopted for the preparation of the modified Marshall Specimen is the same as that used in the control mixtures described above. Marshall Stability test is conducted on the stabilized HMA in all samples of 100 mm diameter and 63.5 mm height by applying 75 blows on each face as per ASTM procedure (ASTM D1559, 2004). These specimens were prepared by mixing the filler material with the graded aggregates at optimum binder content. The filler content in these specimens were varied from 0.5% - 3% by weight of aggregates. The mixing and compaction temperatures are kept as 165°C and 150°C respectively. After compaction, the samples were cured in air before Marshall Stability tests were conducted on them.

2.7. Determination of Properties of the Mix

In this study, apart from stability-flow test, the properties that are of interest include Theoretical specific gravity (G_t), Bulk Modulus (G_{mb}), Bulk Density (ρ), Effective specific gravity (Gse), Voids in Total Mixture (*VTM*), Volume of Bitumen (V_b), Effective bitumen content (Pbe), Void in Mineral Aggregate (*VMA*), and Voids Filled with Asphalt (*VFB*). These calculations are discussed next.

- ***Theoretical specific gravity of the mix (G_t)*:** The theoretical specific gravity (G_t) is the specific gravity without considering air voids, and was obtained by:

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}}$$ Eqn. 3.1

Where W_1 is weight of coarse aggregate in the total mix, W_2 is weight of fine aggregate in the total mix, W_3 is weight of filler in the total mix, W_b is weight of bitumen in the total mix, G_1 is apparent specific gravity of coarse aggregate, G_2 is apparent specific gravity of fine aggregate, G_3 is apparent specific gravity of filler, and G_b is apparent specific gravity of bitumen.

- ***Bulk Modulus of mix (G_{mb})*:** The bulk specific gravity or the actual specific gravity (***G_{mb}***) of the mix is the specific gravity considering air voids and was found by:

$$G_{mb} = \frac{W_a}{W_a - W_w}$$ Eqn. 3.2

Where W_a is weight of mix in air, and W_w is weight of mix in water.

- ***Effective Specific Gravity of Aggregate:*** When based on the Maximum Specific (Gmm) of a bituminous mixture, the Effective Specific Gravity of the aggregate, (Gse), includes all void spaces within the aggregate particles, except those that absorb bitumen, and is determined using:

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$ Eqn. 3.3

Where,

Ps = Aggregate content, percent by total weight of mixture

Pb = Bitumen content, percent by total weight of mixture

Gse = Effective specific gravity of aggregate

Gb = Specific gravity of bitumen

- ***Effective bitumen content of mix (Pbe)*:** The effective bitumen content does not include absorbed bitumen. It is calculated using:

$$P_{be} = P_b - \frac{P_{ba} P_s}{100}$$ Eqn. 3.4

Where,

Pbe = Effective bitumen content, percent by total eight of mixture

Pb = Bitumen content, percent by total eight of mixture

Pba = Absorbed bitumen, percent by total weight of aggregate

Ps = Aggregate content, percent by total weight of mixture

- ***Bulk Density of Mix (ρ)*****:** The bulk density of each mix was calculated from the bulk specific gravity as follows:

$$\rho = G_{mb} \text{x } 1000(\text{kg/m}^3) \quad \text{Eqn. 3.5}$$

- ***Percent Air voids (Vv) (VTM):*** The air voids in compacted asphalt concrete mixture consists of the small air spaces between the coated aggregate particles. The Air voids (*Vv*) percentage for the samples was is obtained by:

$$V_v = \frac{(G_t - G_m)100}{G_t} \quad \text{Eqn. 3.6}$$

Where, G_t is theoretical specific gravity of the mix, and G_m is bulk or actual specific gravity of the mix.

- ***Percent Volume of Bitumen*** **(V_b) *(Pb):*** The volume of bitumen (V_b) is the percent of volume of bitumen to the total volume and given by:

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1+W_2+W_3+W_b}{G_m}} \quad \text{Eqn. 3.7}$$

Where, W_1 is weight of coarse aggregate in the total mix, W_2 is weight of fine aggregate in the total mix, W_3 is weight of filler in the total mix, Wb is weight of bitumen in the total mix, Gb is apparent specific gravity of bitumen, and Gm is bulk specific gravity of mix.

- ***Voids in Mineral Aggregate (VMA):***Voids in mineral aggregate (VMA) is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen, given by:

$$\text{VMA} = \text{Vv} + \text{Vb} \quad \text{Eqn. 3.8}$$

Where, Vv is percent air voids in the mix, and Vb is percent bitumen content in the mix.

- ***Voids Filled with Bitumen (VFB)*****:** Voids filled with bitumen (VFB) are the voids in the mineral aggregate frame work filled with the bitumen, calculated as:

$$VFB = \frac{V_b \times 100}{VMA} \quad \text{Eqn. 3.9}$$

Where, Vb is percent bitumen content in the mix, and VMA is percent voids in the mineral aggregate.

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		

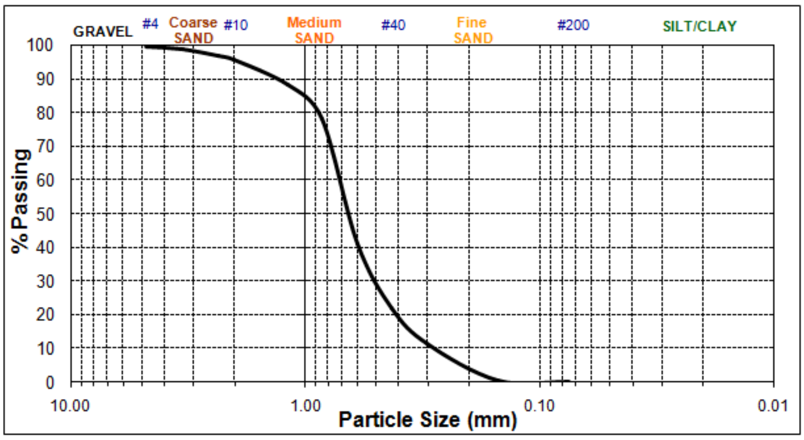


Figure2. *Particle Size distribution for Sand*

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

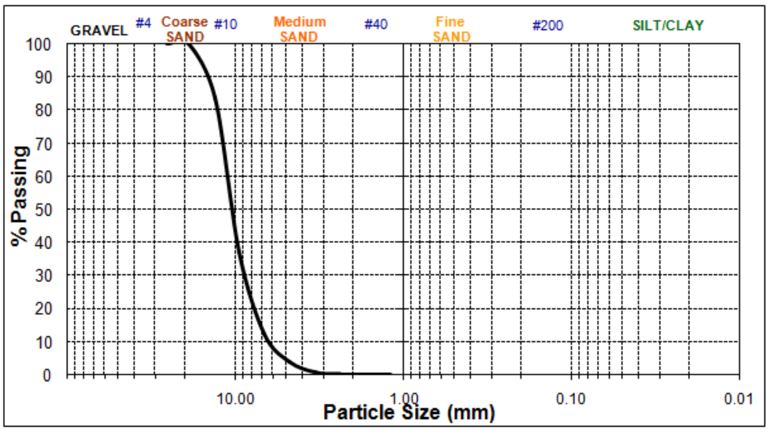


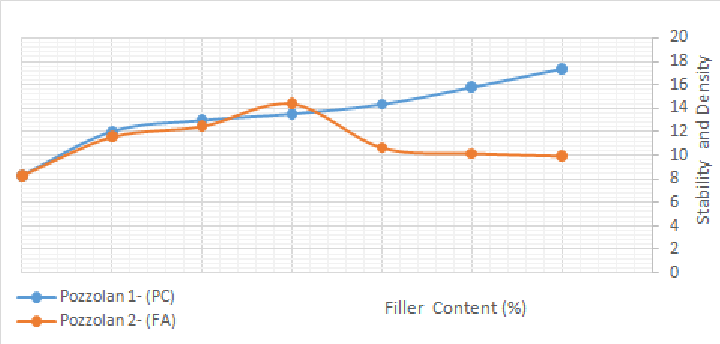
Figure3. *Particle Size distribution for Gravel*

Table3. *Schedule of Mix proportion for Aggregates*

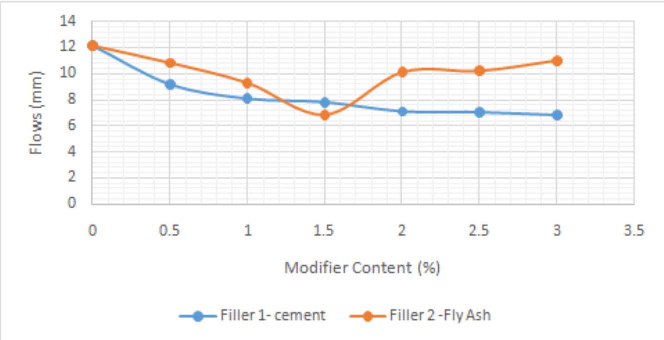
Sieve (in.)	Sieve (mm)	Specification Limit	% passing Aggregate A (Gravel)	% passing Aggregate B (Sand)	Mix Proportion (0.60A+0.40B)	Tolerance
3/4”	19.1	100	100.0	100.0	100.0	±6
½”	12.7	76-92	91.1	100.0	94.7	±6
3/8”	9.52	64-79	43.3	100.0	66.0	±5
No. 4	4.75	40-60	8.6	99.7	45.0	±5
No.10	1.18	23-37	2.7	87.4	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 Design Properties of Asphalt Concrete Modified with Mineral Fillers @ Optimum*

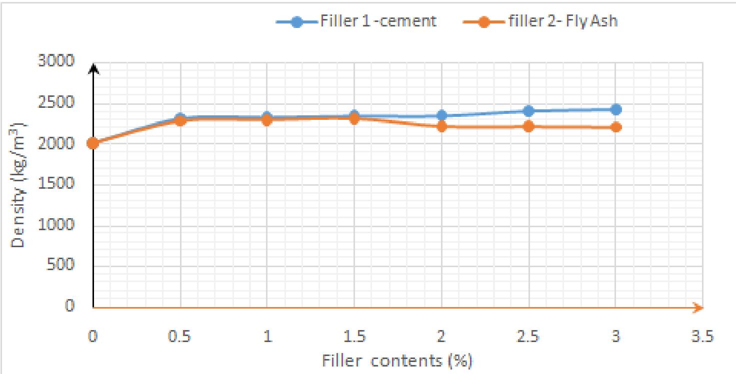
Fillers Contents (%)	Stabilities (N)		Flows (mm)		Densities (Kg/m^3)	
	PC	FA	PC	FA	PC	FA
0.0	8315.02	8315.02	12.132	12.132	2002.107	2002.107
0.5	12049.8	11.60561	09.189	10.81296	2306.337	2279.18
1.0	12993.2	12.51423	08.100	9.282598	2321.754	2294.416
1.5	13531.3	14.44752	07.830	6.86105	2338.498	2310.963
2.0	14343.4	10.67732	07.133	10.10774	2340.074	2213.698
2.5	15777.8	10.1921	07.062	10.2003	2402.112	2210.243
3.0	17355.5	9.9682	06.850	11.0021	2422.031	2200.987



FigA. *Variation of Stability and Density against Filler contents*



FigB. *Variations of Flows against Modifier Contents*



FigC. *Variation of Densities against filler content*

3. DISCUSSION

3.1. Variation of Marshal Stability at Varying Modifier Content

As illustrated in fig A and fig C, stability of the modified mixes increased linearly with increasing filler content for all modifier contents. From Table S-D, it is seen that for the unmodified mixes stability varied by 45% from 8315.02N for the unmodified mix (0%) to 12049.80N upon addition of 0.5% PC. Addition of 1.0% and 1.5% PC further increased stability by 56% and 39% to 12993.2N and 13531.3N respectively. However, at 2%, 2.5% and 3.0% PC content, stability varied by 72%, 89.8% and 52% to 14343.4N, 15777.8 and 17355.5N respectively. Indicating that further increase in PC content with filler content of the stability of the modified asphalt concrete mix can drop stability as the percentage increase dropped 73% from the peak percentage.

Similarly, for Fly Ash (FA) of the mixes, stability follows the same trend, increasing linearly with a corresponding increase in filler content and peaks at 1.5% of the filler contents. For the unmodified briquettes category, stability varied by 40% upon addition of 0.5% FA. Then For 1% and 1.5% FA content, stability increased by 34% and 42% respectively when compared with the unmodified mix. Again, at 2%, 2.5% and 3.0% FA content, stability values decreased to 28%, 23% and 20% respectively, indicating that further addition of FA would reduce the strength of the mix.

3.2. Variation of Density at Varying Modifier Content

Also, for Density of PC there was a linear increase by 15%, 16%, 17%, 17%, 20% and 21% by adding 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% PC contents respectively when compared with unmodified sample. Interestingly, there was a continuous increase in the density property of the asphalt concrete by varying increase in the filler content as illustrated in Table S-D and Fig C of the *Densed mix*.

Similarly, for Fly Ash (FA) of the mixes, Density follows the same trend, increasing linearly with a corresponding increase in filler content and peaks at 1.5% of the filler contents. For the unmodified briquettes category, density varied by 14% upon addition of 0.5% FA. Then For 15(-)%, 1.0% and 15(+)% FA content, density decreased by 11%, 10% and 9.9% respectively when compared with the unmodified mix; at 2%, 2.5% and 3.0% FA content, density values decreased indicating that further addition of FA would reduce the densification of the mix. Therefore, the trend establishes that 1.5% FA content is the threshold modifier content to achieve maximum density because further addition of FA caused a decrease in the density of the modified HMA concrete.

4. CONCLUSION

From the laboratory investigations of both the unmodified and PC and FA modified HMA concrete for heavy traffic condition, it is clear to see that the addition of PC and FA into the mixture produced significant improvements in the properties of the mixtures. However, it is important to note the following points:

- Threshold PC content to attain maximum stability corresponds to 3.0% by weight if the aggregates at optimum binder content; this means that further addition of PC would result in reduction in the density of the asphalt concrete while 1.5% FA content was the threshold r the second modifier.
- The rate of influence of PC on the density HMA concrete increases as the fillercontent increases from 0% to 3.0% PC contents, then decreases linearly from 2.0% to 3.0 FA contents.

Conclusively, The analysis for the modifiedHMA concrete showed improved performance of the pavement due to addition of ordinary Portland cement and Fly Ash, the following recommendations are provided considering the scope, limitation and general findings:

- Portland cement can serve as an excellent material for the modification of HMA concrete for such desirable properties as has improved stability, stiffness, durability, and resistance to stripping and Density (Densification).
- The findings as contained in this paper could serve as a source of literature for subsequent research with respect to the subject matter.
- Finally, modifying HMA concrete with ordinary Portland cement and Fly Ash or any other mineral filler should be conducted thoroughly especially with respect to mixing and durability studies.

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APPENDICES

Rivers State University

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Department of Civil Engineering

Civil Engineering Laboratory

APPENDIX I. *Specific Gravity of Coarse Aggregate*

Specific Gravity Test Form (Coarse Aggregate)

BS 1377:1975

ST PARAMETERS	TEST 1	TEST 2
WEIGHT OF BOTTLE ONLY (g) ……..……… M_1	770.5	770.7
WEIGHT OF BOTTLE AND DRY SAMPLE (g) ……….….. M_2	1260.8	1250.7

WEIGHT OF BOTTLE, SAMPLE AND WATER (g) ……….M_3	1701.3	1692.2
WEIGHT OF BOTTLE AND WATER (g) ………….M_4	1389.0	1383.1
$G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$	2.75	2.81
AVERAGEG_s	2.78	

TESTED BY Engr. Daniel A. Nyebuchi CHECKED Byass. Prof. E.A Igwe date: 2019

APPENDIX II. *Specific Gravity of Fine Aggregate*

Specific Gravity Test Form (Sand)

BS: 1377:1975

TEST PARAMETERS	TEST 1	TEST 2
WEIGHT OF BOTTLE ONLY (g) ……..….……M_1	26.2	26.2
WEIGHT OF BOTTLE AND DRY SAMPLE (g) …………..…M_2	88.8	88.8
WEIGHT OF BOTTLE, SAMPLE AND WATER (g) ……….M_3	117.4	117.4
WEIGHT OF BOTTLE AND WATER (g) ………….M_4	78.3	78.3
$G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$	2.66	2.66
AVERAGEG_s	2.66	

APPENDIX III. *Specific Gravity of Modifier*

Specific Gravity Test Form (PSA)

BS: 1377:1975

TEST PARAMETERS	TEST 1	TEST 2
WEIGHT OF DENSITY BOTTLE (W_1)……gms	25	25
WEIGHT OF BOTTLE AND DRY SAMPLE (W_2)……gms	70	70
WEIGHT OF BOTTLE, SAMPLE AND WATER (W_3)……gms	101.3	102.8
SPECIFIC GRAVITY $G_s = \frac{W_2 - W_1}{50 - (W_3 - W_2)}$	2.4	2.6
AVERAGEG_s	2.5	

APPENDIX IV. *Bitumen Penetration Test*

Standard Penetration Test Form

BS: 4691/3235

TEST PARAMETERS	TEST 1	TEST 2	TEST 3	Average
Test Temperature (^{0}C)	25	25	25	25
Time (s)	5	5	5	5
Penetration	68	65	67	66.7

APPENDIX V. *Bitumen Viscosity Test*

Bitumen Viscosity Test Form

BS: 4693

TEST PARAMETERS	TEST 1	TEST 2	Average
Test Temperature (^{0}C)	60	60	60
Volume of bitumen that falls inside beaker	50	50	50
Time (s)	68.1	70.5	69.3

APPENDIX VI. *Bitumen Softening Point Test*

Bitumen Softening Point Test Form

BS: 4691/3235

TEST PARAMETERS	TEST 1	TEST 2	TEST 1	Test 2
	Ball 1	Ball 2	Ball 1	Ball 2
Temperature at softening point	50	49	49	50
Softening Point	49.5			

APPENDIX VII. *Specific Gravity of Bitumen*

Specific Gravity Test Form (Bitumen)

BS: 1377:1975

TEST PARAMETERS	TEST 1	TEST 2
WEIGHT OF DENSITY BOTTLE (W_1)……gms	41	
WEIGHT OF BOTTLE AND SAMPLE (W_2)……gms	58.6	
WEIGHT OF BOTTLE, SAMPLE IN WATER (W_3)……gms	17.2	
SPECIFIC GRAVITY $G_s = \frac{W_2-W_1}{W_3}$	1.02	

Citation: *Igwe, Aleruchi Enwuso, et.al, "Improving Densibility and Mix Design Properties of Modified Asphalt Concrete for Esal>10^6 using Mineral Fillers", International Journal of Constructive Research in Civil Engineering, 6(2), pp. 26-37. DOI: http://dx. doi.org/10.20431/2454-8693.0602003.*