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Characterizing Mix Design and Stiffness Properties of Asphalt Concrete Mixtures Partialy Replaced With Laterite Rock as Coarse Aggregate

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ABSTRACT: It is a fact that the excessive exploitation of any natural resources leads to depletion of that resource, which is also the case of granite that is used in civil engineering construction works. For us to halt the depletion rate of granite; we need to search for alternative materials to be used as partial replacement for granite as coarse aggregate. This research work evaluated whether or not laterite rock can be used efficiently as partial replacement for conventional granite as coarse aggregate. In other to validate the study, characterization of materials was done with respect to dynamic modulus using laterite rock as partial replacement for granite between 5-25% by weight of the conventional granite for asphalt concrete mixtures. Tests were carried out under varying frequencies of 0.1, 1, 4, and 5Hz respectively. The result obtained revealed that as the content of laterite rock increased the stiffness of the pavement material reduced.

KEYWORDS: Laterite Rock Aggregate, Granite, Material Classification, Mix Design Properties, Dynamic Modulus.

I. INTRODUCTION

Laterite rock has been used as an alternative to granite in several tropical regions, this decision is due to the vast abundant, cost and alarming rate at which granite has been exploited, a fact that was also attested to by (Kasthurba et al., 2015). Acording to Nisha (2018), laterite is a residual ferruginous rock, commonly found in tropical regions and has close genetic association with bauxite. Ata and Adesanya (2007) assessed the effects of applied stress on the modulus of elasticity and modulus of deformability of laterized concrete. In their result they concluded that increase in the level of applied stress brings about decrease in modulus of elasticity and modulus of deformability, but both increase with an increase in strength. It is worthy of note that (Elayesh 2009) reported in his work, that the strength of normal laterite concrete is lower than the normal crushed granite concrete. Nevertheless, no researcher has looked at replacing granite partially with laterite rock in hot mix asphaltic concrete. In this research, the theoretical model and data from the controlled samples from the marshal test procedure was analyzed and collected to obtain the best information for assessing the design and elastic properties of the asphalt concrete mixture when laterite rock is contained in the concrete. The objective of this work is to characterize the suitability of laterite rock as partial replacement for conventional granite in hot mix asphalt concrete with respect to design properties stability, flow and air voids. Also to do same with respect to stiffness of asphalt concrete mixture.

II. MATERIALS AND METHODS

2.1 Sample Collection

The materials used for the preparation of the asphalt concrete samples were collected from different sources, and they include asphalt, coarse and fine aggregate. The asphalt was gotten from Setraco Asphalt plant at Elele while the aggregate (Gravel, laterite rock and Sand) used were obtained from market dealers at Mile 3 Market, Diobu, Port Harcourt. Likewise, the laterite rock was also obtained from market dealers at Mile 3 Market, Diobu, Port Harcourt.

2.2 Sample Preparation

Classification tests was carried out on materials in preparation of the samples which include: specific gravity, viscosity, softening point and penetration for bitumen and that of aggregates include: specific gravity test, particle size distribution, water absorption and Los Angeles Abrasion (See Table 1). Three samples were prepared for each test to get more adequate results such that data curves plotted showed optimum values. Percentage replacement of laterite rock was done for 5%, 10%, 15%, 20% and 25%

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respectively under loading frequencies of 0.1Hz, 1Hz, 4Hz and 5Hz respectively. Thereafter, samples were checked for suitability using Marshall Mix Design specifications (ASTM D6927; 1979). Stability, Flow and Air voids were determined and there graphs plotted accordingly, poission's ratio, stresses, strains and elastic modulus were also determined after which model equations were used to determine the dynamic modulus of the pavement.

2.3 Model Equation Adopted to Determine Stiffness Property (Asphalt Institute, 1993) Dynamic Modulus E^*

The Asphalt Institute, predictive model for stiffness and in particular dynamic modulus was used for the study presented in Huang's Pavement Analysis and design textbook (1993) as in equation 1-6

$$E^* = 100{,}000\ (10\beta_1\ ) \qquad (1)$$

$$\beta_1 = \beta_3 \ \ 0.000005\beta_2 \ \ - 0.00189\beta_2 f^{-1.1} \qquad (2)$$

$$\beta_2 = \beta_4^{\ 0.5} T^{\beta_5} \qquad (3)$$

$$\beta_3 = 0.553833 + 0.028829(P_{200} f^{\ -0.1703}) - 0.03476V_a + 0.07037\lambda + 0.9317\ f^{\ -0.02774} \qquad (4)$$

$$\beta_4 = 0.483V_b \qquad (5)$$

$$\beta_5 = 1.3 + 0.49825\log f \qquad (6)$$

Where,
E^* = Dynamic modulus
f = Loading Frequency
T = Temperature
V_a = Volume of air void
V_b = Volume of bitumen
λ = Asphalt Viscosity at 77° F
P_{200} = Percentage by weight of aggregates passing No 200(%)
$P_{77° F}$ = Penetration @77° F

III. RESULTS (SEE TABLES 1-4 & FIGURES 1-2)

Results obtained from preliminary laboratory test and calibrations are tabulated in the following tables as follows.

Table 1: Bitumen Classification and Specific Gravity Test Results.

Material	Bitumen	Sand	Granite	Laterite Rock
Specific Gravity	1.03	2.78	2.71	2.60
Grade Binder	60/70	-	-	-
Penetration Value (mm)	58.3	-	-	-
Viscosity (Secs)	59	-	-	-
Softening Point (^{0}C)	43.5	-	-	-

Table 2: Sieve Analysis Test for Granite (BS: 812-103; 1985)

SIEVE (in)	NO (mm)	MASS RETAINED	PERCENTAGE RETAINED	PERCENTAGE PASSING
3/4"	19.1	0	0	100
1/2"	12.7	15	0.73	99.27
3/8"	9.52	945	46.57	53.43
1/4"	6.35	572	73.31	26.69
No. 4	4.75	250	86.44	13.56

No. 8	2.36	158	94.10	5.90
No. 16	1.18	33	96.23	3.77
No. 30	0.600	11.5	97.35	2.65
No. 50	0.300	11.5	98.15	1.85
No. 100	0.150	30	99.60	0.4
No. 200	0.075	6	99.89	0.11
Pan		2	99.99	0.01

Table 3: Sieve Analysis Test for Sand (BS: 812-103; 1985)

SIEVE (in)	NO (mm)	MASS RETAINED	PERCENTAGE RETAINED	PERCENTAGE PASSING
3/8"	9.52	8.1	1.62	98.38
1/4"	6.35	29.1	7.44	92.56
No. 4	4.75	17.1	10.86	89.14
No. 8	2.36	50.1	20.88	79.12
No. 16	1.18	72.1	35.30	64.70
No. 30	0.600	108.1	56.92	43.70
No. 40	0.425	69.1	70.74	29.26
No. 50	0.300	92.1	89.16	10.84
No. 100	0.150	54.1	99.98	0.02
No. 20	0.075	0	0	0

Table 4: Sieve Analysis Test for Laterite Rock (BS: 812-103; 1985)

SIEVE (in)	NO (mm)	MASS RETAINED	PERCENTAGE RETAINED	PERCENTAGE PASSING
3/4"	19.1	0	0	100
1/2"	12.7	577.1	46.70	100
3/8"	9.52	251.5	20.35	53.30
1/4"	6.35	150.7	12.19	32.95
No. 4	4.75	64.4	5.21	20.76
No. 8	2.36	49.2	3.98	15.55
No. 16	1.18	26.3	2.13	11.57
Pan		116.6	9.44	9.44
Total		1,235.8	100	0

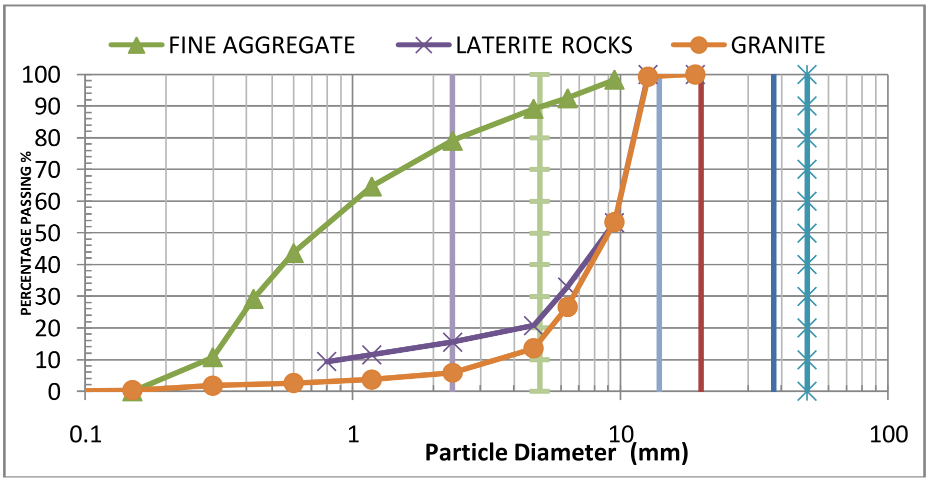

Figure 1: Particle Size Distribution Graph of Various Aggregates Used

Table 5: Experimental Mix Design Properties with Partial Replacement of Laterite Rock (ASTM D6927; 1979)

REPLACEMENT WITH LATERITE ROCK at OBC (%)	STABILITY (KN)	FLOW (0.25mm)	AIR VOID (%)	VMA (%)
0	6850 (OK)	8.64 (OK)	2.79 (Not OK)	25.44 (OK)
5	6749 (OK)	8.88 (OK)	2.86 (Not OK)	34.02 (OK)
10	6710 (OK)	10.08 (OK)	2.96 (Not OK)	34.37 (OK)
15*	6680 (OK)	10.88 (OK)	3.34 (OK)	35.55 (OK)
20	4983 (Not OK)	16.96 (Not OK)	3.43 (OK)	36.38 (OK)
25	4680 (Not OK)	20.00 (Not OK)	3.97 (OK)	40.14 (OK)
Limiting values From Standards (ASTM D6979,1979)	6,672 (Minimum)	8 – 16	3 – 5	14 (Minimum)

Table 6: Results of Dynamic Modulus at 15% Replacement of Granite with Laterite Rock

Frequency (Hz)	Dynamic Modulus (Ib/In^2) at 15% Replacement	Limiting Dynamic Modulus not to be Exceeded (lb/in^2) from (Gudipudi 2016)
0.1Hz	86,735.38 (OK)	93,694.55
1Hz	136,996.02 (OK)	200,007.40
4Hz	175,652.65 (OK)	335,037.78
5Hz	183,050.93 (OK)	335,037.78

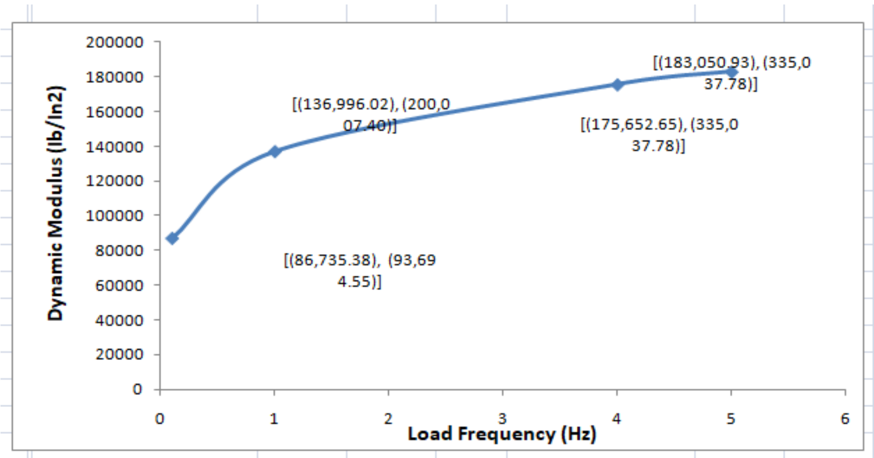

Figure 2: Variation of Dynamic Modulus with Varying Frequencies

IV. DISCUSSION

4.1 Mix Design Properties

(a) As presented in Table 5 above, at 15% partial replacement with laterite rock. The experimental result for stability is 6680KN and the minimum limiting value as presented in (ASTM D6927, 1979) is 6672KN which presents that stability value obtained from the experiment is above the limiting value and shows that the experiment is OK.

(b) As presented in Table 5 above, at 15% partial replacement with laterite rock. The experimental result for flow is 10.88mm and the limiting value as presented in (ASTM D6927, 1979) is between 8-16 which presents that flow value obtained from the experiment is within the range of limiting values and shows that the experiment is OK.

(c) As presented in Table 5 above, at 15% partial replacement with laterite rock. The experimental result for Air void is 3.34% and the limiting value as presented in (ASTM D6927, 1979) is between 3-5 which presents that Air void value obtained is between the ranges of the limiting values showing that the experiment is OK.

(d) As presented in Table 5 above, at 15% partial replacement with laterite rock. The experimental result for VMA is 35.55% and the minimum limiting value as presented in (ASTM D6927, 1979) is 14% which presents that VMA value obtained is above the minimum limiting values showing that the experiment is OK.

4.2 Determination of Stiffness, Dynamic Modulus

Table 6 and Figure 2 above presents the result of Dynamic modulus at 15% replacement using laterite rock at varying loading frequencies. At loading frequency of 0.1Hz the experimental result is 86,735.38Ib/In^2 and the maximum limiting value according to (Gudipudi, 2016) is 93,694.55Ib/In^2 which presents that at 0.1Hz value obtained from the experiment is less than the maximum limiting value showing that the experiment is OK.

At 1Hz the experimental result is 136,996.02Ib/In^2 and the maximum limiting value according to (Gudipudi, 2016) is 200,007.40Ib/In^2 which presents that at 1Hz value obtained from the experiment is less than the maximum limiting value showing that the experiment is OK.

At 4Hz the experimental result is 175,652.65Ib/In^2 and the maximum limiting value according to (Gudipudi, 2016) is 335,037.78Ib/In^2 which presents that at 4Hz value obtained from the experiment is less than the maximum limiting value showing that the experiment is OK.

Similarly, at loading frequency of 5Hz the experimental result is 183,050.93Ib/In^2 and the maximum limiting value according to (Gudipudi, 2016) is 335,037.78Ib/In^2 which presents that at 5Hz value obtained from the experiment is less than the maximum limiting value showing that the experiment is also OK.

V. CONCLUSION

From the results obtained an observations made from this paper the following conclusions are made.

i. That laterite rock can be successfully used to replace conventional granite as coarse aggregate in HMA concretes.
ii. That replacement shall not exceed 15% of the conventional granite in order to have a safe and durable pavement.
iii. At 15% replacement of conventional granite using laterite rock both mix design properties and stiffness (Dynamic Modulus) criteria was satisfied.

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