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Correlation Models of Asphalt Institute and Witczak 1-40D Dynamic Moduli for Periwinkle and Snail Shell Modified HMA

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Abstract— Dynamic modulus, E* a stiffness parameters of hot mix asphalt (HMA) was investigated in this study. The Marshall mix design method was used to investigate the varying amount of periwinkle shell ash (PSA) and snail shell ash (SSA) as mineral fillers on the E* of HMA. E* was calculated with the two most used predictive models, Asphalt institute and Witczak 1-40D models. In this study also, two models were proposed to correlate the two predictive models by regression analysis using the SPSS software. The models include a Quadratic Polynomial and Logarithmic. Laboratory results showed a similar pattern for the two models. E* increased with percentage increase of the mineral filler up to 1%. Further increase in mineral filler did not show any increase in E*. The results also showed that E* values of HMA modified with PSA where higher than those of SSA. In summary, the results showed that the Quadratic Polynomial and Logarithmic models can favourably correlate Asphalt Institute and Witczak 1-40D equations with very high R^2 values up to 99% for SSA and PSA respectively.

Index Terms— Correlation, Dynamic Modulus, Periwinkle Shell Ash, Snail Shell Ash, Asphalt Institute, Witczak, HMA, Quadratic Polynomial, Logarithmic.

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1 INTRODUCTION

To achieve more durable and higher performing pavements in the most economical way, pavement design and construction is moving towards a more mechanistic based design method.

The characterization of material properties is one key aspect of mechanistic based pavement design [6] and one of such properties is the stiffness of the hot mixed asphalt (HMA), which influences tensile strain levels. Stiffness of HMA can be characterized by many parameters including; flexural stiffness, dynamic modulus (E*), resilient modulus etc. However, E* is the most used especially in Mechanistic Empirical Pavement Design Guide (MEPDG).

Dynamic modulus (E*) which is defined as the degree of HMA's resistance to deformation under sinusoidal loading, can be used to characterize the viscoelastic behaviour of the HMA concretes by determining the effects of temperature and frequency on the stiffness of the HMA concrete under dynamic loading.

Dynamic modulus has been satisfactorily demonstrated to be dependent on two parameters: temperature and frequency. The various ways in which these parameters influence dynamic modulus has been consistently reported by researchers over the years [10], [13], [14]

HMA concrete is made up of mainly two components (sometimes three or more); aggregate and binder. The binder and aggregate have many properties of their own which directly or indirectly influences the general response of the HMA mixture. Therefore, it is only rational to conclude that the properties of each of these two components will further influence the dynamic modulus of HMA.

Model equations for the determination of E* has been developed by so many, however, the problem arising from the different researchers are that:

I. The different results from the models from different agencies/organizations/researchers do not always converge.
II. Results from some models seem more accurate than others, e.g. while some models consider temperature, a very important parameter, others do not.
III. Also, the determination of E* from some of the models are more cumbersome while some others are not.

Thus, developing a correlation between these models has become a precipitated necessity.

The use of Periwinkle shell and Snail Shell ashes and other marine shells as full or partial replacement in HMA mixtures and other construction materials, has become a necessary way of curbing the environmental challenges created by the indiscriminate dumping of these shells and to help reduce the cost of producing HMA and other construction materials.

Periwinkle *(Turritella communis),* an edidle sea snail which is dark, oval shaped with hard shell and Snail a small greenish-blue spiral shaped marine creature are found in the uhdeltaic regions of South-South of Nigeria which include; Cross-River, Rivers, Akwa-Ibom and Bayelsa [5], [16].

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2 Materials and methods

2.1 Materials

The materials used for the preparation of the asphaltic concrete which simulates actual flexible pavement under investigation in this research work were collected from different sources. The bitumen used was obtained from Asca-Ringardas Nigeria Limited while the aggregates (gravel and sand) used were obtained from Earthbase Construction Company. The modifiers used: Periwinkle and snail shells were obtained directly from the the market dealers at Mile 3 Diobu, Port Harcourt, Nigeria.

2.2 Materials Preparation and Methods

The materials were prepared using Marshal mix design procedure for Asphalt Institute – Mix Design methods for Hot-mix Asphalt paving (1956). The techniques include the preparation of a series of test specimens for a range of bitumen contents such that test data curves showed well defined optimum values. Tests were scheduled on the bases of 0.5 percent increments of bitumen content with at least 3 bitumen contents above and below the optimum asphalt content. For us to provide adequate data, three replicate test specimens were prepared for each set of bitumen content used. For the unmodified asphalt concrete samples, the aggregates were first heated for about 5 minutes before asphalt was added to allow for absorption into the aggregates. After which the mix was poured into a mould and compacted on both faces with 35 blows using a 6.5kg rammer falling freely from a height of 450mm. Compacted specimens were subjected to bulk specific gravity test, stability and flow, density and voids analyses at a temperature of 60^0C. The results obtained were used to determine optimum asphalt content of the unmodified asphalt concrete. Periwinkle shell ash (PSA) and Snail shell ash (SSA) broken down into pieces and further to fine powder such hat it is capable of passing through a 90µm sieve, were then added at varying amounts (0.5-2.5%) by weight of f the the asphalt at optimum asphalt content and then re-designed using the same Marshal design procedure already stated above to produce PSA and SSA modified asphalt concrete having the varying mix design properties. The varying values of mix design properties obtained by modifying with PSA and SSA was inputed into our Asphalt Institute and Witczak 1-40D model equations to obtain varying E* values used for this research work.

The Aphalt Institute predictive model for the determination of E* as presented in Huang's Pavement Analysis and Design textbook was used in this research work:

$$E^* = 100{,}000\left(10^{\beta}{}_1\right) \tag{1}$$

$$\beta_1 = \beta_3 + 0.000005\beta_2 - 0.00189\beta_2 f^{-1.1} \tag{2}$$

$$\beta_2 = \beta_4{}^{0.5} T^{\beta_5} \tag{3}$$

$$\beta_3 = 0.553833 + 0.028829(P_{200} f^{-0.1703}) - 0.03476V_a + 0.07037\gamma + 0.\lambda + 0.931757f^{-0.02774} \tag{4}$$

$$\beta_5 = 0.483V_b \tag{5}$$

$$\beta_5 = 1.3 + 0.49825 log f \tag{6}$$

$$\lambda = 29{,}508.2(P_{77°F})^{*2.1939} \tag{7}$$

Where
E* = Dynamic modulus (psi)
F = Loading frequency (Hz)
T = Temperature (^{o}F)
V_a = Volume of air voids
Λ = Asphalt viscosity at 77^{o}F (10^6 poises)
P_{200} = %by weight of aggregates passing No. 200 (%)
V_b Volume of bitumen
P_{77oF} = penetration at 77^{o}F or 25^{o}C

Also used for the determination of dynamic modulus is the Witczak 1-40D by Witczak and Bari in 2006:

$$log E^* = -0.349 + 0.754(|G^*{}_b|^{-0.0052})*$$
$$(6.65 - 0.032P_{200} + 0.0027(P_{200})^2 + 0.011P_4 - 0.0001(P_4)^2$$
$$+0.006P_{38} - 0.00014(P_{38})^2 - 0.08V_a - 1.06\ (V_{beff}/V_a + V_{beff}))$$
$$+((2.56 + 0.03V_a + 0.71\ (V_{beff}/V_a + V_{beff}) + 0.012P_{38} - 0.0001(P_{38})^2$$
$$-0.01P_{34})/(1+e^{(-0.7814-0.5785 \log|G^*b|+0.8834 \log\delta b)}) \tag{8}$$

Where:
E* = dynamic modulus of mix, psi
|Gb*| = dynamic shear modlulus of binder, psi
P_{200} = % passing #200 sieve
P_4 = cumulative % retained on #4 sieve
P_{38} = cumulative % retained on 3/8 in. sieve
P_{34} = cumulative % retained on 3/8 in. sieve
V_a = air voids, % by volume
V_{beff} = effective binder content.

3.0 DEVELOPING MODEL FIT BETWEEN ASPHALT INSTITUTE AND WITCZAK 1-40D DYNAMIC MODULI

The correlation models were focused on testing non-linear models that can best be used to describe the model fit between Ashpalt Institute and Witczak 1-40D models, the proposed non-linear models used in testing the correlation includes:

a) Quadratic polynomia model – Y =ax^2 + bx + c (9)
b) Logarithmic model – Y = a ln(x) + b (10)

Where
Y = dynamic modulus of bituminous concrete from Asphalt institute
X = dynamic modulus of bituminous concrete from Witczak 1-40D
a,b,c = material coefficients to be determined

The method of analysis was executed by writing a non-linear regression equation that satisfies the condition of the general form of the dynamic modulus model and inputting stringed variables into the SPSS software for non-linear analysis.

To use the IBM SPSS statistic software in solving a non-linear regression, the variables (dependent and independent) are first collated into different cells in the **"Data Views"** dialogue box. After which the variables are stringed and coded into another dialogue box called the **"Variable Views Cell"**. Finally, a model syntax that satisfies the condition of the general form of the fatigue cracking model is then developed [15].

a. Quadratic Polynomial Model

The non-linear model syntax polynomial is of the form as shown below;

$$Y = a * (X * * 2) + b * X + c \qquad (11)$$

Where,

Y = dependent variable (dynamic modulus of bituminous concrete from asphalt institute)

X = independent variable (dynamic modulus of bituminous concrete from Witczak 1-40D)

a, b and c are coefficients to be determined from the non-linear regression equation.

The command (**) is used to show when raising a variable to the power of the coefficient in the same bracket while the command (*) is used for multiplication.

b. Logarithmic Model

The non-linear model syntax for the logarithmic equation is of the form as shown below;

$$Y = a * \ln(X) + b \qquad (12)$$

Where,

Y = dependent variable (dynamic modulus of bituminous concrete from asphalt institute)

X = independent variable (dynamic modulus of bituminous concrete from Witczak 1-40D)

a and b are coefficients to be determined from the non-linear regression equation.

4.0 RESULTS

The results obtained from the preliminary laboratory test are tabulated as follows:

TABLE 1
LABORATORY TEST RESULTS OF MATERIALS

Material	PSA	SSA	Asphalt	Sand	Gravel
Specific Gravity	2.85	2.88	1.03	2.78	2.71
Grade of Binder material	-	-	60/70	-	-
Mix proportion (%)	-	-	-	41	51
Viscosity of Binder (poise)	-	-	-	-	-
Softening Point	-	-	$49^{o}c$	-	-
Penetration Value (mm)	-	-	69	-	-

TABLE 2
MIX DESIGN PROPERTIES OF UNMODIFIED ASPHALT

A/C (%)	STABILITY (KN)	FLOW (0.25mm)	DENSITY (Kg/m^3)	AIR VOIDS (%)	VMA (%)
3.5	12.51	2.11	846	5.25	28.8
4.0	12.53	2.29	1383	4.8	26.81
4.5	17.13	2.42	1284	4.4	22.1
5.0	27.32	2.55	1267	3.9	21.783
5.5	22.75	3.16	1273	3.5	21.1
6.0	18.6	3.39	1269	3.1	27.48

TABLE 3
MIX DESIGN PROPERTIES OF HMA MODIFIED WITH PSA AT 4.5% OAC

% OF PSA	MIX DESIGN PROPERTIES			
	STABILITY (KN)	FLOW (mm)	DENSITY (Kg/m^3)	AIR VOID (%)
0	4.42	13.75	2198.14	14.47
0.5	6.1	11.38	2389.16	7.04
1.0	8.82	10.4	2465.15	4.08
1.5	6.87	10.94	2429.54	5.47
2.0	5.45	11.56	2345.15	8.75
2.5	5.35	11.63	2286.12	11.05

TABLE 4
MIX DESIGN PROPERTIES OF HMA MODIFIED WITH SSA AT 4.5% OAC

% OF SSA	MIX DESIGN PROPERTIES			
	STABILITY (KN)	FLOW (mm)	DENSITY (Kg/m^3)	AIR VOID (%)
0	4.42	13.75	2198.14	14.47
0.5	8.99	11.96	2385.54	7.18
1.0	15.20	7.50	2463.55	4.14
1.5	12.55	9.80	2428.14	5.52
2.0	6.70	10.10	2325.16	9.53
2.5	5.21	12.85	2221.41	13.56

The results of the dynamic modulus for the various modifiers are as presenteded below, the results were obtained by applying (1)-(8).

TABLE 5
DYNAMIC MODULUS OF HMA MODIFIED WITH PSA

% OF PSA	DYNAMIC MODULUS E* (Mpa) AT A FREQUENCY OF 50Hz	
	ASPHALT INSTITUTE	WITCZAK 1-40
0	568.2424726	354.1066872
0.5	1189.427045	641.9397266
1.0	1389.472204	813.3415247
1.5	1317.427781	727.9631261
2.0	1031.136819	55.718219
2.5	824.7607507	465.7251014

TABLE 6
DYNAMIC MODULUS OF HMA MODIFIED WITH SSA

% OF SSA	DYNAMIC MODULUS E* (Mpa) AT A FREQUENCY OF 50Hz	
	ASPHALT INSTITUTE	WITCZAK 1-40
0	568.2424726	354.1066872
0.5	1176.759289	634.7432589

1.0	1387.568278	809.2988045
1.5	1313.589419	724.7960878
2.0	959.1917571	525.9353778
2.5	629.1720622	380.7215698

By applying (9) and (10) in the SPSS program the following result were obtained

a) **Quadratic Polynomial model**

By applying (9) in the SPSS program the following results were obtained:

TABLE 7
QUADRATIC POLYNOMIAL MODEL (PSA MODIFIED)

X	a	b	c	PREDICTED Y VALUES	MEASURED Y VALUES
354.1067	-0.002	4.075	-641.386	550.8154	568.2425
641.9397	-0.002	4.075	-641.386	1150.345	1189.425
813.3415	-0.002	4.075	-641.386	1349.932	1389.472
727.9631	-0.002	4.075	-641.386	1265.203	1317.428
559.7182	-0.002	4.075	-641.386	1012.897	1031.137
465.7251	-0.002	4.075	-641.386	822.644	824.7608

The experimental coefficients were determined as follows as shown in Table 7, a = -0.002; b = 4.075; c = -641.386, with a correlation value of $R^2 = 0.999$

The resulting prediction model equation in syntax form becomes.

Y = -0.002 * (X ** 2) + 4.075 * X -641.386 (13)

TABLE 8
QUADRATIC POLYNOMIAL MODEL (SSA MODIFIED)

X	a	b	c	PREDICTED Y VALUES	MEASURED Y VALUES
354.1067	-0.002	4.1	-645.785	555.2693	568.2425
634.7433	-0.002	4.1	-645.785	1150.864	1176.759
809.2988	-0.002	4.1	-645.785	1362.411	1387.568
724.7961	-0.002	4.1	-645.785	1275.22	1313.589
525.9354	-0.002	4.1	-645.785	957.334	959.1918
380.7216	-0.002	4.1	-645.785	625.2756	629.1721

The experimental coefficients were determined as follows as shown in Table 8, a = -0.002; b = 4.1; c = -645.785, with a correlation value of R2 =0.999.

The resulting prediction model equation in syntax form becomes.

Y = -0.002 * (X ** 2) + 4.1 * X – 645.785
(14)

a) **Logarithmic Model**

By applying (10) in the SPSS program the following results were obtained:

TABLE 9
LOGARITHMIC MODEL (PSA MODIFIED)

X	a	b	PREDICTED Y VALUES	MEASURED Y VALUES
354.1067	1020.837	-5428.31	563.5941	568.2425
641.9397	1020.837	-5428.31	1170.886	1189.427
813.3415	1020.837	-5428.31	1412.474	1389.472
727.9631	1020.837	-5428.31	1299.262	1317.428
559.7182	1020.837	-5428.31	1030.969	959.589
465.7251	1020.837	-5428.31	843.3006	629.1721

The experimental coefficientwere determined as follows as shown in the Table 9,

A = 1020.837; b = -5428.31, with a correlation value of $R^2 = 0.997$.

The resulting prediction model equation in syntax form becomes.

Y = 1020.837 * ln (X) – 5428.31
(15)

TABLE 10
LOGARITHMIC MODEL (SSA MODIFIED)

X	a	b	PREDICTED Y VALUES	MEASURED Y VALUES
354.1067	1020.837	-5443.584	563.223	568.2425
634.7433	1020.837	-5443.584	1160.488	1176.759
809.2988	1020.837	-5443.584	1409.115	1387.568
724.7961	1020.837	-5443.584	1296.259	1313.589
525.9354	1020.837	-5443.584	968.0502	959.1918
380.7216	1020.837	-5443.584	637.3871	629.1721

The experimental coefficient were determined as follows as shown in Table 10, a = 1023.376; b = -5443.58, with correlation value of $R^2 = 0.998$.

The resulting prediction model equation in syntax form becomes.

Y = 1023.376* ln (X) – 5443.58
(16)

5.0 DISCUSSION

The following findings were observed in course of analysing the result:

- The SSA modified HMA concrete showed similar patterns of behaviour as those of the PSA modified HMA concrete. That is E* increased linearly up to 1% of the snail shell ash content after which further additions of the non bituminous modifiers resulted in a decrease of E*. This holds true for both Asphalt institute and Witczak 1-40D
- It was also observed from Table 5 and 6 above that the E* derived from Witczak 1-40D model are more conservative than those from Asphalt institute.
- The results of the study were compared using linear regression analysis as shown in Table 7 – 10. The comparison shows that R^2 for measured values and predicted values are high and correlates favorably.
- The proposed correlation models can be used to predict dynamic modulus from the measure dynamic modulus derived from Asphalt institute or Witczak 1-40D models with very high R^2 values of

about 99%.

6 CONCLUSIONS

The conclusion from the above research can be deduced as follows:

1. The incremental addition of the modifiers to the HMA improved on the stiffness (dynamic modulus) of the asphalt concrete and got to a peak value at 1% for both modifiers and for the Asphalt institute and Witczak 1-40D models.
2. The values for stiffness (dynamic modulus) derived using the Witczak 1-40D models showed more conservative values than those derived using the Asphalt Institute model.
3. The proposed correlation models can be used to predict dynamic modulus from the measured dynamic modulus derived from Asphalt Institute or Witczak 1-40D models with very high R^2 values of 95% and above.
4. From the two proposed models, the Quadratic Polynomia model gave the best correlation with an R^2 of 0.999, followed by the Logarithmic with R^2 of 0.998.

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