Material characterization and statistical evaluation of properties of hot mix asphalt concrete (HMAC) used in wearing course of road pavement; Southern Nigeria

Roland Kufre ETIM ▪ Department of Civil Engineering, Akwa Ibom State University, Ikot Akpaden, Nigeria ▪ rolandetm@aksu.edu.ng
Idorenyin Ndarake USANGA ▪ Department of Civil Engineering, Akwa Ibom State University, Ikot Akpaden, Nigeria
David Ufot EKPO ▪ Department of Civil Engineering, Akwa Ibom State University, Ikot Akpaden, Nigeria
Imoh Christopher ATTAH ▪ Department of Civil Engineering, Akwa Ibom State University, Ikot Akpaden, Nigeria

Érkezett: 2022. 04. 15. ▪ Received: 15. 04. 2022. ▪ https://doi.org/10.14382/epitoanyag-jsbcm.2022.29

Abstract
An investigative study was carried out on the assessment of engineering properties of asphaltic concrete used for pavement construction in Akwa Ibom State, South-south, Nigeria. A total of 225 compacted samples of wearing course asphaltic concrete were obtained from three different asphalt plants in Eket, Oron and Uyo designated as D, E, and G, respectively. The test results based on the outcome of the Marshal Stability for the three different asphalt plants ranged from 7.51-13.36 kN, 9.36-11.34 kN and 8.26-9.46 kN with corresponding flow values which ranged from 3.33-3.94 mm, 2.40-3.48 mm and 2.73-3.19 mm for asphalt plants D, E, and G, respectively. The test outcomes revealed that a good number of the test samples were within the benchmark of the Nigeria General Specifications for roads. Three predictive models were built for the estimation of Marshall Stability for the three different sites. Based on the outcome of t-test (paired two sample for means) and analysis of variance (ANOVA) single factor, there was no significant difference between the experimented values and model formulated results. Also, the formulated model yielded an excellent coefficient of determination (R^2) of 0.9513, 0.9777 and 0.9777 for the three sites. This excellent coefficient of determination reflect the models could be used in prediction of stability strength. The correlation statistic and their respective p-values of each of the independent variables, BIT, VIM and VFB has shown to contribute more than the other variables in building the established models and thus expedient in forecasting the performance of asphalt pavements.

Keywords: asphaltic concrete, stability flow, regression models, correlation statistics
Kulcsszavak: aszfaltbeton, stabilitási áramlás, regressziós modellek, korrelációs statisztikák

Roland K. ETIM
is a lecturer in the Department of Civil Engineering, Akwa Ibom State University, Ikot Akpaden, Nigeria. His research interest is in the field of geotechnical and geo-environmental engineering as well as sustainable cleaner materials for civil engineering infrastructures. He is a member of several professional societies.

Idorenyin N. USANGA
is a lecturer in the Department of Civil Engineering, Akwa Ibom State University, Ikot Akpaden. He is a registered Engineer with COREN and a corporate member of the Nigeria Society of Engineers. He has a Master's degree in Highway and Transportation Engineering with several well-known scholarly articles. He is currently working as a consultant in Akwa Ibom Roads and Other Infrastructure Maintenance Agency (AKROIMA).

David U. EKPO
is a lecturer in Akwa Ibom State University. He is a registered Engineer with COREN and a corporate member of the Nigeria Society of Engineers. He has a Master's degree in Civil Engineering with specialization in Geotechnical and Geo-environmental Engineering. He has published scholarly articles in Geotechnical and Geo-environmental Engineering.

Imoh C. ATTAH
is a lecturer in the Department of Civil Engineering, Akwa Ibom State University, Ikot Akpaden, Nigeria. His research focus is in: optimization of civil engineering materials, soil re-engineering, sustainable infrastructures and construction engineering. He is a member of several professional societies.

1. Introduction

Road infrastructure remains very fundamental in the modern day society because of the role it plays in urbanization. It makes sizeable investment concerning economic, social and cultural development of any country [1]. It also offers a platform that encourage the interchanging of goods, movement of human and as well include places that are difficult to access within a particular time [2]. However, distresses on our roads have resulted to various type of failure on our pavement. Pavement distresses ranging from rutting, shoving, raveling, transverse cracking, longitudinal cracking, potholes etc. are predominant on Nigerian roads. It is so disheartening that these roads are frequently being reconstructed overtime without making any frantic effort to examine the possible causes of their perpetual failures. Numerous factors which include but not limited to geotechnical, design and specifications, improper selection of materials, methods of construction, geomorphological etc. might influence the overall performance of highway pavement structures [3-7]. Also, studies have also shown that failure of wearing courses of road pavement are caused by the poor stability of sub-grade and sub-based materials. The stability is linked to the very low California bearing ratio (CBR) values which is a critical parameter to the design and stability of pavement structures. Therefore, researches on stabilization of poor soil materials to meet the benchmark for sub-grade and sub-base have being reported in several studies [8-17, 39-46]. Several studies have also reported poor quality of asphalt concrete as another main cause pavement failure [18-20].

However, wearing course of flexible pavement are built or design to withstand certain ups and downs in terms of physical climatic and environmental conditions during the pavement infrastructure life span. It is well known that some of our flexible pavements in this part of the country tend to experience some deterioration, cracks etc. due low quality of construction materials, poor supervision and climatic conditions. Also, this layer (wearing course), being an essential part of the road structure is saddled with the responsibilities of enhancing even and stable distribution of axle wheel loads to all other layers below (i.e. binder coarse, base, subbase and subgrade) while ensuring that durability is not compromised. The hot mix asphalt (HMA) concrete is basically made of a combination of aggregates and asphalt cement (bitumen). The aggregate which consists of coarse and fine particles constitutes about 90% of the total volume of HMA. They usually act as the structural skeleton of the pavement. Ahmedzade and Sengoz [21] reported that the performance of asphalt pavement is largely dependent on the properties of the aggregates. The asphalt cement on the other hand, plays the role of bonding the mixtures together. The superior service performance in ensuring a stable, durable and water resistance pavement structures renders asphaltic concrete as one of the most utilized pavement materials [22].

Few studies that have examined the engineering properties of asphalt concrete with respect to its stability, flow, penetration, and viscosity in Nigeria has been in the Southwest. Recent studies by Akinleye and Tijani [23], concluded that; none of the samples met all the requirements specified by the Nigerian General Specifications (NGS) [24]. This might possibly be due to the use of poorly graded mineral aggregates coupled with poor and inadequate bitumen content that led to a mix with poor stability and excess voids. Osunkunle et al. [25] assessed the engineering properties of asphaltic concrete produced in the Southwestern region of Nigeria. The results of the test carried out on the bitumen and asphalt concrete were in conformity with the specifications of Federal Ministry of Works and Housing. However, the results of the water absorption fell below the minimum requirements. The authors therefore concluded that the water absorption might have impaired the strength of the asphalt concrete thereby leading to failure of the pavement structure before its design age in that region. The durability of flexible pavements was studied by Obeta and Njoku [26] and they concluded that the use of poor quality materials, inadequate thickness of pavement surface, improper mix design and lack of routine maintenance as the key factors responsible for low durability. The study by Alkawaaz and Qasim [27] revealed that low durability potential of the wearing course layer is one of the major reasons for distresses in asphalt pavement which reduced serviceability limit of highways.

Model generation from established data is one of the accurate process to corroborate as well as explain the usefulness of some highway laboratory results. Having said this, a mechanistic empirical approach was used to develop a model aimed at predicting the rutting performance of pavement structures [28]. Furthermore, Bala et al. [29] applied multivariable regression models for prediction of composite nano silica / polymer asphalt mixture of optimum binder content (OBC). Also, prediction equations of properties of asphalts material were achieved from large experimental data using statistical regression approach [30-33]. Baldo et al [34] numerically predicted the mechanical response of asphalt concretes for road pavement using artificial neural networks (ANN).

Asphaltic concrete pavement which has been otherwise used as flexible pavements is a complex system of multiple layers of various materials that combines irregular traffic loading and fluctuating environmental conditions which includes temperature, moisture and oxidation rates [35]. This makes it more challenging for highway engineers to build realistic models for predicting durability performance of asphaltic pavements. Since the performance of asphalt concrete pavement is closely related to the properties of the aggregates, it therefore becomes imperative to properly evaluate the performance and behaviour of asphalt concrete. The paucity of literatures on the assessment of the quality of asphalt pavement in the region under consideration needs an authoritative data to be established. Hence, the necessity of the studies. This study aims to critically examine the engineering properties of asphaltic concrete for basically Marshal Stability and flow and in turn compares it with the minimum benchmark of the NGS for wearing course. This is with a view of accessing its suitability for construction in Akwa Ibom State. Furthermore, since stability is a key parameter in asphaltic concrete mix design, a multiple variable regression model relating stability and flow will also be generated. The need to develop relevant models from laboratory results and data are central in engineering investigation and analysis. This is with the aim of saving time and or cost in certain aspect of evaluations. In the light of this, the model generated is expected to provide the pathway within the various processes of asphalt mix design, structural design, construction and rehabilitation of pavement structures. Therefore, if the stability and flow are known, the rigorous stress of the laboratory can be avoided thereby providing precise information as regards the performance of the asphalt pavement.

2. Materials and methods

2.1 Materials

2.1.1 Bitumen

Based on information available in the course of this study, the bitumen was obtained from Eleme petrochemical Port-Harcourt, Rivers State, Nigeria. The different test protocol used and the properties of bitumen that has been study is presented in *Table 1*.

2.1.2 Aggregates

Based on available information, the aggregate used in this study was collected at location outcrops of igneous rocks in Akampa quarry site (latitude; 5^{O}0'30.64"N, longitude 7^{o}53'22.84"E), Cross river state, Nigeria. The aggregates consist of fine aggregate having maximum sizes of 5 mm and coarse aggregate having maximum sizes of 5 mm and above. The various test properties and test protocols adopted for the aggregate is presented in *Table 2*.

Test	Standard
Penetration test	AASHTO D T-49
Specific gravity	BS 1377
Softening point	ASTM D36-95 or AASHTO D T-53
Flash point	AASHTO D T-48

Table 1 Characteristic properties of bitumen and standard of testing used
1. táblázat A bitumen jellemző tulajdonságai és az alkalmazott vizsgálati szabványok

Properties	Test code method
Gs (Coarse aggregate)	ASTM C127
Gs (fine aggregate)	ASTM C128
Sieve analysis	BS 1377
Los Angeles Abrasion test, %	ASTM C131/ EN 1097-8
Aggregate crushing value ACV, %	BS 812-114
Flakiness index %	EN 933-3

Table 2 Properties of aggregate and bitumen
2. táblázat Az aggregátum és a bitumen tulajdonságai

2.1.3 Marshall testing

The Marshall test was continuously carried out in a span of twelve months to cover all year-round season. The Marshall test involves using standard cylindrical molds (102 mm in diameter and 64 mm in height). Hot samples were intermittently collected from various batches of asphalt concrete samples from the asphalt plants. The hot mixture is placed in the mold and was compacted at regulated temperature of 130 °C by application of 75 blows of a Marshall hammer on each side of the specimen. It is generally expected that the average of three samples should be tested for each set. However, more than three samples test was considered because of the bulk of production which needed to be tested to ensure uniformity and consistency in batching and mixing that were maintained throughout the production process from the respective asphalt plants. Therefore, the report was based on the average of minimum of five samples whose values were very close. Tests results (Marshall stability and flow) was compared for quality based on pavement specifications of NGS [24] for wearing course. Marshall Stability and flow were determined according to ASTM D2172, ASTM C136 and ASTM D6927-05.

2.1.4 Formulation of regression model

The formulation of regression models follows the guiding principles in [36]. The Marshall stability is a very important parameter in asphaltic concrete mix design. The acceptable range in this study is based on the specification of NGS [24]. Generally, the Marshall properties depend on the volumetric analysis by weight of dense asphalt concrete obtained from Marshall Tests. Stability of dense asphaltic concrete (AC) is typically a factor for accepting optimal and adequate design of wearing course asphaltic concrete. Stability is thus selected in this study and modelled for various asphalt plant designated as D, E and G located in Eket, Oron and Uyo, respectively. Laboratory results was obtained from several batches of asphalts concrete (wearing course) collected from the three asphalts plant. Based on available information, the asphalts concrete collected from these plants were produced following adequate /optimum asphalt mix design that meets Marshall stability requirement according to NGS [24] specification for wearing course. The laboratory was maintained at room temperature during testing. The outcomes of the tests were used to assess the uniformity and consistency in the several batches of asphalt concrete paving mix produced for each unit and compared with the specifications provided by the Federal Ministry of Works, Nigeria. Consequently, the Marshall stability for each of the asphalt production unit were modelled using the concept of multiple variable regression with each variable having fifteen data points. Each of the fifteen data point was an average of five close values obtained during testing as stated earlier in this report.

2.1.5 Regression model for Marshall Stability

Independent variable (Y) identified and referred here as Marshall stability (S) was achieved based on identified independent variables x_1, x_2, x_3 and x_4 referred as bitumen content (BIT), void in the mix (VIM), void in total mix dry aggregates (VMA) and void filled with bitumen (VFB), respectively. x_1, x_2, x_3 and x_4 from i to nth number of various specimens of the selected asphalt production site was obtained from volumetric analysis (by weight) of specimen which was compacted to dense asphalt concrete (wearing course). The mode of compaction was is in accordance with ASTM D6927-15 with all other necessary laboratory conditions constant. Based on the multivariable factors considered in this study, the general formula for multilinear regression is presented as:

$$Y = a + b_1x_{1(i)} + b_2x_{2(i)} + b_3x_{3(i)} + b_4x_{4(i)} + \varepsilon; \quad (1)$$

Where: x_1, x_2, x_3 and x_4 is bitumen content (BIT), void in the mix (VIM), void in total mix dry aggregates (VMA) and void filled with bitumen (VFB), respectively; a, b_1, b_2, b_3, and b_4 are constants called regression constants. i = 1,2,3,...n data points for various asphalt production plant denoted as D, E and G. The laboratory study was done under steady condition with significant precision devoid of erratic or random error. Based on this, ε = zero random error due to the high level of accuracy with which the laboratory investigation was achieved. *Eq. (1)* is the linear form for the selected variables whose requirement are central to having good wearing course for sustainable pavement structure. The relationship of the SMRE for the different variables in the Marshall test is required to attain the stability that meets the wearing course specifications as required in design criterions for wearing course of HMAC. For the set of populated data points or results and introducing or as well as minimizing the sum of least square, we obtained from *Eq. (1)*;

$$\begin{aligned}
\sum y &= an + b_1\sum x_1 + b_2\sum x_2 + b_3\sum x_3 + b_4\sum x_4 \\
\sum yx_1 &= a\sum x_1 + b_1\sum x_1^2 + b_2\sum x_1x_2 + b_3\sum x_1x_3 + b_4\sum x_1x_4 \\
\sum yx_2 &= a\sum x_2 + b_1\sum x_1x_2 + b_2\sum x_2^2 + b_3\sum x_2x_3 + b_4\sum x_2x_4 \\
\sum yx_3 &= a\sum x_3 + b_1\sum x_1x_3 + b_2\sum x_2x_3 + b_3\sum x_3^2 + b_4\sum x_3x_4 \\
\sum yx_4 &= a\sum x_4 + b_1\sum x_1x_4 + b_2\sum x_2x_4 + b_3\sum x_3x_4 + b_3\sum x_4^2
\end{aligned} \quad (2)$$

However, *Eq. (2)* may well also be transformed to the format of a matrix which is now basically written in the form;

$$AX = B \quad (3)$$

where;
A = square matrix (5×5) that represent independent variables
B = column matrix that represent dependent variables
X = column matrix that represent linear regression constants so that,

$$\begin{bmatrix} \sum y \\ \sum yx_1 \\ \sum yx_2 \\ \sum yx_3 \\ \sum yx_4 \end{bmatrix} = \begin{bmatrix} n & \sum x_1 & \sum x_2 & \sum x_3 & \sum x_4 \\ \sum x_1 & \sum x_1^2 & \sum x_1x_2 & \sum x_1x_3 & \sum x_1x_4 \\ \sum x_2 & \sum x_1x_2 & \sum x_2^2 & \sum x_2x_3 & \sum x_2x_4 \\ \sum x_3 & \sum x_1x_3 & \sum x_2x_3 & \sum x_3^2 & \sum x_3x_4 \\ \sum x_4 & \sum x_1x_4 & \sum x_2x_4 & \sum x_3x_4 & \sum x_4^2 \end{bmatrix} \begin{bmatrix} a \\ b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} \quad (4)$$

Using Gauss reduction method [48] or (MATLAB), *Eq. (4)* can be solved and a, b_1, b_2, b_3, and b_4 are established. Thus the MLR represented in *Eq. (1)* which expresses the Marshall Stability model could be expressed as;

$$S_i = a + b_1(BIT)_{(i)} + b_2(VIM)_{(i)} + b_3(VMA)_{(i)} + b_4(VFB)_{(i)}; i = 1, 2, 3, \dots \dots n \quad (5)$$

Additional statistical tool was deployed to check the adequacy of the models. The experimented and predicted responses from linear model were paired and subjected to t-test (paired two sample for means) and analysis of variance (ANOVA) single factor. The study is limited to laboratory-based performance of wearing course hot mix asphalt concrete with specified limit based on NGS [24] requirement.

3. Results and discussion

3.1 Characterization of materials used

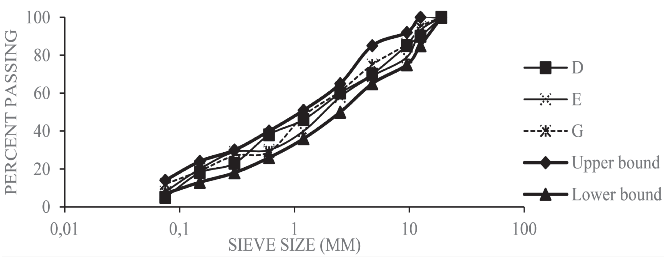

Fig. 1 Typical gradation of aggregates from binder course from site D, E and G
1. ábra A D, E és G helyszínről származó kötőanyagból származó aggregátumok tipikus osztályozása

Test	Site D	Site E	Site G	Specified limit by NGS [24]
Penetration test	64	67	65	60-70 at 25°C
Specific gravity	1.02	1.01	1.01	1.01-1.05 at 25°C
Softening point	49°C	53° C	51° C	48-50°C
Flash point	255	258	256	250 °C

Table 3 Characteristic properties of bitumen
3. táblázat A bitumen jellemző tulajdonságai

Aggregate properties	Asphalt concrete sites			Specified limits NGS [24]
	D	E	G	
Gs (Coarse aggregate)	2.681	2.681	2.681	-
Gs (fine aggregate)	2.678	2.678	2.678	-
Average % passing 75um sieve	87	90	88	≥ 75%
Los Angeles Abrasion test, %	17	17.4	23	≤ 25%
Aggregate crushing value ACV, %	22	23	21.4	≤ 30%
Flakiness index %	18	20	20.5	≤ 35%

Table 4 Properties of aggregate and bitumen
4. táblázat Az adalékanyag és a bitumen tulajdonságai

The typical particle size gradation of aggregates from the three site presented in *Fig. 1*. It is observed that the results of sample D, E and G fell within the upper and lower boundary of the gradation envelope for wearing course asphaltic concrete. Typical properties of the bitumen and aggregate used in this study is shown in *Table 3* and *4*.

3.2 Asphalt concrete properties for wearing course

The wearing course properties of asphalt concrete mix for the three asphalt plants site denoted as D, E and G are presented in *Table 5-7*. The results of each samples revealed the following engineering properties of asphalt; marshal stability, flow, bitumen content, voids in total mixture and voids filled with bitumen. Based on the results, the volumetric properties, Marshall Stability and flow meet the pavement requirement for wearing course NGS (1997) (see *Table 8*). It is likely that the asphalt concrete from the three asphalt plants could withstand traffic load without getting cracked or easily failed. This is because the results suggest that if failure would occur on the pavement structure, it would not necessarily be linked to the quality of asphalt mix. Although the quality of hot mix asphaltic concrete may in some cased be compromised due to poor material handling/ preparation, efficiency of the asphalt plant, etc., therefore is also relevant to note that probable failure in service could be due to poor ground preparation (sub grade and subbase), excessive wheel load beyond that which the pavement was designed, drainage condition.

Sample description	BIT (%)	VIM (%)	VMA (%)	VFB (%)	S (kN)	F mm
D1	6.2	3.49	14.82	76.47	8.85	3.33
D2	6.13	3.3	15.24	78.33	8.05	3.78
D3	5.3	3.62	15.88	77.18	7.51	3.94
D4	6.4	2.78	15.31	81.82	9.66	3.80
D5	6.6	3.23	15.16	78.67	10.46	3.76
D6	5.75	3.49	14.89	76.57	7.78	3.70
D7	7.1	2.71	14.93	81.82	12.07	3.71
D8	6.8	2.61	14.36	81.81	11.27	3.56
D9	7.3	3.13	14.48	78.35	12.88	3.59
D10	6.5	2.68	14.59	81.64	10.06	3.62
D11	6.1	3.3	14.82	77.7	8.45	3.68
D12	5.7	3.08	15.01	79.51	7.65	3.72
D13	7.35	2.89	15.16	80.91	13.36	3.76
D14	6.57	3.11	15.12	79.42	10.25	3.75
D15	6.43	3.73	15.24	75.54	9.5	3.78

Table 5 Properties of compacted dense asphalt concrete specimens from site D
5. táblázat A D helyszínről származó tömörített sűrű aszfaltbeton próbatestek tulajdonságai

Sample description	BIT (%)	VIM (%)	VMA (%)	VFB (%)	S (kN)	F mm
E1	6.8	2.27	10.4	78.18	9.95	3.41
E2	7.6	1.98	10.4	80.97	10.87	2.50
E3	6.5	2.84	14.17	79.96	9.36	3.48
E4	7.3	2.26	15.12	85.06	10.55	2.84
E5	7.8	2.05	14.06	85.38	11.34	2.40
E6	6.7	2.87	15.2	81.14	9.62	3.38
E7	7.5	2.7	14.78	81.7	10.69	2.60
E8	7.3	1.81	14.48	87.51	10.4	2.80
E9	7.9	3.44	14.63	76.48	11.22	2.30
E10	6.8	3	14.74	79.63	9.81	3.39
E11	6.9	2	15.47	87.09	9.82	3.21
E12	7.1	2.35	15.58	84.9	10.18	2.97
E13	6.86	2.83	15.58	81.81	9.74	3.30
E14	7.43	2.86	15.58	81.67	10.72	2.70
E15	6.92	2.65	15.58	82.96	9.75	3.10

Table 6 Properties of compacted dense asphalt concrete specimens from site E
6. táblázat Az E helyszínről származó tömörített sűrű aszfaltbeton próbatestek tulajdonságai

Sample description	BIT (%)	VIM (%)	VMA (%)	VFB (%)	S (kN)	F mm
G1	5.86	4.16	16.07	74.14	9.39	3.15
G2	5.17	5.79	16.41	64.73	8.41	2.78
G3	5.61	4.61	16.78	72.52	9.04	3.01
G4	5.79	4.42	16.33	72.93	9.24	3.11
G5	5.53	4.97	16.67	70.18	9.11	2.97
G6	5.08	5.72	16.26	64.79	8.26	2.73
G7	5.92	4.07	16.82	75.82	9.44	3.18
G8	5.26	5.3	16.22	67.35	8.53	2.82
G9	5.88	4.33	16.74	74.16	9.37	3.16
G10	5.47	4.62	16.07	71.23	8.76	2.94
G11	5.76	4.55	17.56	74.11	9.25	3.09
G12	5.85	4.65	16.82	72.34	9.34	3.14
G13	5.94	4.76	14.24	66.61	9.46	3.19
G14	5.58	5.01	16.78	70.11	8.89	3.00
G15	5.18	5.38	14.43	62.75	8.41	2.78

BIT=Bitumen content in total weight of mix; VIM=Void in the mix; VMA=Void in total mix dry aggregate; VFB=Void filled with bitumen, S = Marshall stability, F = Marshall flow

Table 7 Properties of compacted dense asphalt concrete of specimens from site G
7. táblázat A G helyszínről származó minták tömörített sűrű aszfaltbetonjának tulajdonságai

Properties	Standards as per NGS (1997) [24]
Bitumen content, BIT (%)	4.5 - 6.5
Stability, S (kN)	≥3.5 KN
Flow, F (mm)	2 - 4
Voids in total mix, VIM (%)	3 -5
Voids filled with bitumen VFB (%)	75 -82

Table 8 Standard of asphalt concrete of wearing course
8. táblázat Az aszfaltbeton kopórétegének szabványa

3.3 Developing the regression models

The results of the Marshall test of the compacted hot mix asphaltic wearing course concrete presented in *Table 6-8*, was used in formulation of the multiple regression model equations that show a relationship between five of the variables (S, BIT, VIM, VMA and VFB). From these equations, stability (S) designated Y is the dependent variable and the independent variables are bitumen content (BIT) designated x_1; void in the mix (VIM) designated (x_2); void in total mix dry aggregates (VMA) designated x_3 and void filled with bitumen (VFB) designated x_4. Applying the least square for each of the site we thus have that for asphalt plant D

$$\begin{bmatrix} \sum y \\ \sum yx_1 \\ \sum yx_2 \\ \sum yx_3 \\ \sum yx_4 \end{bmatrix} = \begin{bmatrix} n & \sum x_1 & \sum x_2 & \sum x_3 & \sum x_4 \\ \sum x_1 & \sum x_1^2 & \sum x_1x_2 & \sum x_1x_3 & \sum x_1x_4 \\ \sum x_2 & \sum x_1x_2 & \sum x_2^2 & \sum x_2x_3 & \sum x_2x_4 \\ \sum x_3 & \sum x_1x_3 & \sum x_2x_3 & \sum x_3^2 & \sum x_3x_4 \\ \sum x_4 & \sum x_1x_4 & \sum x_2x_4 & \sum x_3x_4 & \sum x_4^2 \end{bmatrix} \begin{bmatrix} a \\ b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} \quad (6)$$

Therefore

$$\begin{bmatrix} 147.8 \\ 963.14 \\ 459.2 \\ 2213.08 \\ 11713.4 \end{bmatrix} = \begin{bmatrix} 15 & 96.23 & 47.15 & 225.01 & 1185.74 \\ 96.23 & 622.11 & 300.83 & 1442.03 & 7615.7 \\ 47.15 & 300.83 & 149.97 & 708.18 & 3716.73 \\ 225.01 & 1442.03 & 708.18 & 3377.28 & 17783.7 \\ 1185.74 & 7615.7 & 3716.73 & 17783.7 & 93797 \end{bmatrix} \begin{bmatrix} a \\ b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} \quad (7)$$

Solving a, b_1, b_2, b_3 and b_4 using Gaussian elimination method we have; a = -224.537; b_1 = 3.299; b_2 = 17.048; b_3 = -3.059; b_4 = 2.600. Thus;

$$Y_D = -224.537 + 3.2992X_1 + 17.0482X_2 - 3.059X_3 + 2.600X_4 \quad (8)$$

Also for asphalt plant E, *Table 5* refers

$$\begin{bmatrix} 154.02 \\ 1106.45 \\ 388.73 \\ 2212.87 \\ 12676.1 \end{bmatrix} = \begin{bmatrix} 15 & 107.41 & 37.91 & 215.77 & 1234.44 \\ 107.41 & 771.63 & 271.19 & 1543.92 & 8840.34 \\ 37.91 & 271.19 & 98.82 & 549.21 & 3104.61 \\ 215.77 & 1543.92 & 549.21 & 3144.14 & 17783.7 \\ 1234.44 & 8840.34 & 3104.61 & 17785 & 101731 \end{bmatrix} \begin{bmatrix} a \\ b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} \quad (9)$$

Solving a, b_1, b_2, b_3 and b_4 using Gaussian elimination method we have; a = 4.717; b_1 = 1.422; b_2 = -0.3755; b_3 = 0.0469; b_4 = -0.0529

$$Y_E = 4.717 + 1.422X_1 - 0.3755X_2 + 0.0469X_3 - 0.0529X_4 \quad (10)$$

For asphalt plant G, *Table 6* refers;

$$\begin{bmatrix} 134.9 \\ 756.11 \\ 647.80 \\ 2197.19 \\ 9495.91 \end{bmatrix} = \begin{bmatrix} 15 & 83.88 & 72.34 & 244.2 & 1053.77 \\ 83.88 & 470.31 & 402.52 & 1366.22 & 5906.23 \\ 72.34 & 402.52 & 352.81 & 1176 & 5054.5 \\ 244.2 & 1366.2 & 1176 & 3986.56 & 17187.3 \\ 1053.77 & 5906.23 & 5054.5 & 17187.3 & 74261 \end{bmatrix} \begin{bmatrix} a \\ b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} \quad (11)$$

Solving a, b_1, b_2, b_3 and b_4 using Gaussian elimination method we have; a = 1.158; b_1 = 1.4101; b_2 = -0.0128; b_3 = 0.0225; b_4 = -0.0051

$$\text{Thus, } Y_G = 1.1579 + 1.4101X_1 - 0.0128X_2 + 0.0225X_3 - 0.0051X_4 \quad (12)$$

3.4 Hypothesis using t- statistics and analysis of variance of paired outcome

The variables in experimented and predicted results (*Tables 9-10*) are paired and then subjected to t-test (paired two sample for means) and ANOVA (single factor). Two conditions hypothesis, the null and the alternative hypothesis is fixed. (1) The null hypothesis state that there is no significant difference between the experimental results and predicted outcome of stability and (2) the alternative hypothesis state that there is a significant difference between the experimental test and predicted outcome of stability results. For a two-tail test (inequality), if t Stat < -t Critical two-tail or t Stat > t Critical two-tail, we reject the null hypothesis. Based on the outcome of experimental and predicted results of site D (*Table 9*) and *Table 12*, t Stat = 0.013595 and t Critical two-tail = 2.144787, so t Critical > t Stat. therefore we accept the null hypothesis. However, from the anova results on the experimental and predicted results of site D (*Table 13*), if F > F crit, we reject the null hypothesis. Accordingly, the result has shown that F = 4.61E-06 and F crit = 4.1959 thus F crit > F cal. It is then decided hereafter that we do not reject the null hypothesis. Therefore, the difference between the laboratory observed results and the model outcome was not significant. The model can be said to be adequate for use in predicting the possible stability which must be based on an optimum hot mix design. Similarly, the results of site E and G (*Table 10* and *11*) and verified with t-stat (*Table 13* for E and G) and ANOVA (*Table 14* and *15*) keep on with the same trend as adequacy is attained. The implication of this study is that rather than continuously carrying out design of asphalt concrete especially when the bitumen content is a significant determining factor, it will be necessary to adopt a model based on past laboratory performance of asphalt concrete manufactured based on satisfactory criteria of material specification and design requirement. This will of course save time and cost rather than going into the rigorous laboratory method of testing. It is now evident that simple multiple regression has proffer the opportunity of using other volumetric variables (independent) to predict the stability values of a compacted hot mixed asphalt concrete provided the quality of pavement mix prepared for wearing course meet the pavement service requirement as recommended by NGS (1997) [24].

Sample description	Sexp.	Spred.	Model	Abs. error	% error
D1	8.85	8.90	1	0.0054	0.54
D2	8.05	8.98	1	0.1154	11.54
D3	7.51	6.75	1	0.1015	10.15
D4	9.66	9.86	1	0.0212	2.12
D5	10.46	10.46	1	0.0005	0.05
D6	7.78	7.46	1	0.0412	4.12
D7	12.07	12.14	1	0.0061	0.61
D8	11.27	11.17	1	0.0092	0.92
D9	12.88	12.32	1	0.0436	4.36
D10	10.06	10.22	1	0.0163	1.63
D11	8.45	8.53	1	0.0091	0.91
D12	7.65	7.58	1	0.0090	0.90
D13	13.36	12.97	1	0.0294	2.94
D14	10.25	10.39	1	0.0139	1.39
D15	9.5	10.05	1	0.0574	5.74

Table 9 Experimental and predicted Marshall Stability of asphalt plant D
9. táblázat A D aszfaltgyár kísérleti **és** *előrejelzett Marshall-stabilitása*

Sample description	Sexp.	Spred.	Model	Abs. error	% error
E1	9.95	9.88	2	0.0066	0.66
E2	10.87	10.98	2	0.0104	1.04
E3	9.36	9.33	2	0.0036	0.36
E4	10.55	10.46	2	0.0089	0.89
E5	11.34	11.18	2	0.0142	1.42
E6	9.62	9.59	2	0.0036	0.36
E7	10.69	10.74	2	0.0044	0.44
E8	10.4	10.47	2	0.0063	0.63
E9	11.22	11.30	2	0.0069	0.69
E10	9.81	9.74	2	0.0075	0.75
E11	9.82	9.89	2	0.0075	0.75
E12	10.18	10.17	2	0.0012	0.12
E13	9.74	9.81	2	0.0072	0.72
E14	10.72	10.62	2	0.0097	0.97
E15	9.75	9.90	2	0.0156	1.56

Table 10 Experimental and predicted Marshall Stability of asphalt plant E
10. táblázat Az E aszfaltgyár kísérleti és előrejelzett Marshall-stabilitása

Sample description	Sexp.	Spred.	Model	Abs. error	% error
G1	9.39	9.36	3	0.0037	0.37
G2	8.41	8.42	3	0.0008	0.08
G3	9.04	9.02	3	0.0021	0.21
G4	9.24	9.26	3	0.0027	0.27
G5	9.11	8.91	3	0.0216	2.16
G6	8.26	8.29	3	0.0032	0.32
G7	9.44	9.45	3	0.0010	0.10
G8	8.53	8.53	3	0.0002	0.02
G9	9.37	9.40	3	0.0028	0.28
G10	8.76	8.81	3	0.0062	0.62
G11	9.25	9.24	3	0.0008	0.08
G12	9.34	9.36	3	0.0022	0.22
G13	9.46	9.46	3	0.0003	0.03
G14	8.89	8.99	3	0.0108	1.08
G15	8.41	8.40	3	0.0011	0.11

Sexp. = Stability (experimental); S = Stability (predicted); Abs. error = Absolute error

Table 11 Experimental and predicted Marshall Stability of asphalt plant G
11. táblázat A G aszfaltgyár kísérleti és előrejelzett Marshall-stabilitása

Descrip-tions	D Sexp.	Spred.	E Sexp.	. Spred.	G Sexp.	. Spred.
Mean	9.853333	5.008671	10.268	10.26934	8.993333	8.99298
Variance	3.570067	3.396386	0.372003	0.363711	0.176952	0.172989
Observ.	15	15	15	15	15	15
PC	0.975362		0.98878		0.988791	
HPC	0		0		0	
df	14		14		14	
t Stat	0.013595		-0.05716		0.021799	
P(T<=t) one-tail	0.494672		0.477611		0.491458	
t Critical one-tail	1.76131		1.76131		1.76131	
P(T<=t) two-tail	0.989345		0.955222		0.982916	
t Critical two-tail	2.144787		2.144787		2.144787	

Observ. = Observations; PC = Pearson Correlation; HPC = Hypothesized Mean Difference; df = Degree of freedom

Table 12 T-Test of D, E and G: Paired Two Sample for Means
12. táblázat D, E és G T-próbája: párosított kétmintás átlagértékek

Anova: Single Factor						
Summary						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S	15	147.8	9.85333	3.57006		
Spred	15	147.7781	9.85187	3.39638		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.61E-05	1	1.61E-05	4.61E-06	0.99830	4.19597
Within Groups	97.53033	28	3.48322			
Total	97.53035	29				

Table 13 Analysis of variance: Single factor for D
13. táblázat Varianciaanalízis a D telephelyhez

Anova: Single Factor						
Summary						
Groups	*Count*	*Sum*	*Average*	*Variance*		
S	15	154.02	10.268	0.37200		
Spred	15	154.0402	10.26934	0.36371		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.36E-05	1	1.36E-05	3.69E-05	0.99519	4.19597
Within Groups	10.3	28	0.36785			
Total	10.30001	29				

Table 14 Analysis of variance: Single factor for E
14. táblázat Varianciaanalízis az E telephelyhez

Anova: Single Factor						
Summary						
Groups	Count	Sum	Average	Variance		
S	15	134.9	8.99333	0.17695		
Spred.	15	134.8947	8.99298	0.17298		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9.37E-07	1	9.37E-07	5.36E-06	0.99817	4.19597
Within Groups	4.89918	28	0.17497			
Total	4.89918	29				

Table 15 Analysis of variance: Single factor for G
15. táblázat Varianciaanalízis a G telephelyhez

3.5 Relationship between the experimented and predicted responses

The relationship between the experimented results and predicted responses of stability S obtained from the three models of *Eq. (8)*, *(10)* and *(12)* are presented in *Fig. 2a-c*. The results show a very high R-square values of up to 0.95 indicating that the models are adequate in predicting the stability of wearing course hot mixed asphalt concrete. These results provide further support for the hypothesis that the difference between the laboratory observed results and the model outcome was not significant.

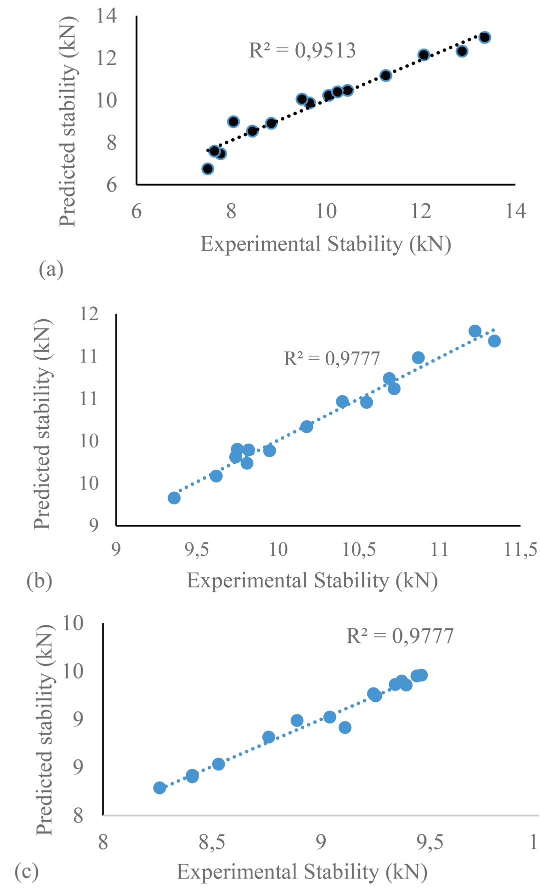

Fig. 2 Relationship between experimented and predicted results for (a) asphalt production plant D (b) asphalt production plant E and (c) asphalt production plant G
2. ábra A kísérleti és az előre jelzett eredmények közötti kapcsolat a) a D aszfaltgyártó üzem, b) az E aszfaltgyártó üzem és c) a G aszfaltgyártó üzem esetében

3.6 Correlation statistics

The correlation statistics (*Tables 16-18*) and their p-values (*Tables 19-21*) relationships between stability, S and other variables; BIT, VIM, VMA, VFB and F derived from Marshall tests, indicate various levels of associations. The results of asphalt plants D, indicate that the correlations between stability values S and BIT (0.9687 $P < 0.05$); VIM (-0.5747 $P < 0.05$); VMA (-0.4035 $P > 0.05$); VFB (0.5243 < 0.05) and F (-0.1778 > 0.05) show that BIT, VIM and VFB has high variable positive and negative correlations values with p-values less 0.05. Also, the correlation of asphalt plant E observed between S and BIT, VIM VFB, and F are (0.9859; $P < 0.05$), (-0.1342; $P > 0.05$); (-0.1833; $P > 0.05$), (0.0309; $P > 0.05$) and (-0.9623; $P < 0.05$), respectively

(See *Tables 9* and *12*). This indicate that bitumen content BIT and Marshall flow, F are well correlated with stability values of wearing course of hot mix asphalt concrete. This finding is in agreement with Bala et al., [29] findings which showed a good correlation between bitumen content Stability and flow. Similarly, the result of hot mix asphalt concrete tested for site G shows the correlation between stability S and BIT (0.9885 P < 0.05); VIM (-0.8886; P < 0.05); VMA (-0.1972 P > 0.05); VFB (0.7925 < 0.05) and F (-0.9885 < 0.05) is an indication that all variables except VMA correlated well with stability. Based on this study, it could be said that stability of wearing course of hot asphaltic concrete is undoubtedly a function of Marshall volumetric properties. Besides all variables showing various degree of relationship with stability for the three asphalts plant, one of the more significant findings to emerge from this study is that bitumen content BIT is a common significant factor that could influence the stability values of the wearing course of a compacted hot mix asphalt concrete. This is observed in the high positive correlation matrix between stability and bitumen (binder) for the three sites considered in this study. A possible explanation to this is based on the fact that the increase in bitumen content in a hot mix asphalt concrete; results in filling of the voids in total mix VIM thereby reducing percentage voids in total mix VIM. Also, it offers additional cohesive and adhesive bonding between the diverse aggregates within the mix thereby increasing percentage voids filled with bitumen VFB. This behavior agrees with the correlation statistics between stability and void variables (VIM and VFB) gotten for the threes asphalt plant site which indicate a negative and positive correlation statistics for VIM and VFB, respectively. Furthermore, the increase in bitumen or binder content stated in this study is based on optimum content which did not exceed the acceptable range or limits provided in the mix design of the project or job specifications. So, the performance of bitumen paving mixture or compacted/dense hot mixed asphaltic concrete is influenced by the unified and adhesive bonding between aggregates and bitumen (binder) [37]. Generally, this study has been able to show that these variables; BIT, VIM and VFB are very critical and pivotal to achieving adequate stability and must be strictly monitored so as to achieve stability S values that would meet the project specification based on optimum design of asphalt concrete. The test (correlation) was successful as it was able to identify critical variables whose contributions are very fundamental and should be looked out for during preliminary laboratory investigation so as to minimize error as well as achieve adequate quality of wearing course asphaltic concrete.

	S	BIT	VIM	VMA	VFB	F
S	1					
BIT	0.9687	1				
VIM	-0.5747	-0.5705	1			
VMA	-0.4035	-0.4820	0.4791	1		
VFB	0.5243	0.4988	-0.9768	-0.2813	1	
F	-0.1778	-0.2607	0.1470	0.7643	0.0263	1

Table 16 Correlation matrix (Pearson) for site D
16. táblázat Korrelációs mátrix (Pearson) a D helyszínhez

	S	BIT	VIM	VMA	VFB	F
S	1					
BIT	0.985909	1				
VIM	-0.13423	-0.09995	1			
VMA	-0.18327	-0.11264	0.353112	1		
VFB	0.030897	0.04936	-0.73694	0.369174	1	
F	-0.96225	-0.98837	0.114038	0.078405	-0.0907	1

Table 17 Correlation matrix (Pearson) for site E
17. táblázat Korrelációs mátrix (Pearson) az E helyszínhez

	S	BIT	VIM	VMA	VFB	F
S	1					
BIT	0.988471	1				
VIM	-0.88856	-0.90064	1			
VMA	0.197214	0.176472	-0.25973	1		
VFB	0.792468	0.793264	-0.90842	0.63736	1	
F	0.988471	1	-0.90064	0.176472	0.793264	1

Table 18 Correlation matrix (Pearson) for site G
18. táblázat Korrelációs mátrix (Pearson) a G helyszínhez

	S	BIT	VIM	VMA	VFB	F
S	0.000					
BIT	0.000	0.000				
VIM	0.025	0.026	0.000			
VMA	0.136	0.069	0.071	0.000		
VFB	0.045	0.058	0.000	0.310	0.000	
F	0.520	0.345	0.595	0.001	0.933	0.000

Table 19 P values of compacted asphalt concrete of site D
19. táblázat D telephely tömörített aszfaltbetonjának P értékei

	S	BIT	VIM	VMA	VFB	F
S	0.000					
BIT	0.000	0.000				
VIM	0.060	0.002	0.000			
VMA	0.380	0.161	0.024	0.000		
VFB	0.123	0.011	0.000	0.629	0.000	
F	0.083	0.000	0.002	0.152	0.011	0.000

Table 20 P values of compacted asphalt concrete of site E
20. táblázat E telephely tömörített aszfaltbetonjának P értékei

	S	BIT	VIM	VMA	VFB	F
S	0.000					
BIT	0.000	0.000				
VIM	0.000	0.000	0.000			
VMA	0.013	0.000	0.000	0.000		
VFB	0.000	0.000	0.261	0.009	0.000	
F	0.630	0.322	0.002	0.789	0.221	0.000

Table 21 P values of compacted asphalt concrete of site G
21. táblázat G telephely tömörített aszfaltbetonjának P értékei

4. Conclusions

The study on analysis of grade of asphalt and bitumen used in pavement construction clearly revealed that asphalt concrete from all the asphalt plant met the requirement for bitumen content, stability and flow when compared to general specification for roads and bridges from Federal Ministry of Works and Housing. The study has also shown that multiple linear regression models developed as a function of stability was adequate and could be used to predict the stability of HMAC designed for wearing course of a road pavement. The study and analysis also identify BIT, VIM and VFB as critical variables that contributed significantly to the stability of a hot mixed asphalt concrete and should be carefully observed in laboratory studies so as to minimize error and achieve optimum mix design that would realize adequate quality. Above all, to achieve good field performance of the asphalt concrete obtained through dedicated modelling from laboratory reports, relevant engineering procedure should be adopted during laying. This include but not limited to ensuring asphalt compaction thickness conform to design provision and also ensure that asphalt pavement surface is subjected to adequate drainage condition.

References

[1] O'Flaherty CA. Evolution of the transport task: C. A. O'Flaherty (ed): Transport planning and traffic engineering. Oxford: Elservier 1997.

[2] Gogoi R, Dutta B. (2020) Maintenance prioritization of interlocking concrete block pavement using fuzzy logic, Inter. J. Pavement Res. Technol. 2020; 13(2): 168-175.

[3] Aghamelu OP, Okogbue CO. Geotechnical assessment of road failure in the Abakaliki Area, Southeastern Nigeria. International Journal of Civil and Environmental Engineering. 2011; 11(2): 12 – 24.

[4] Jegede, G. Effect of soil properties on pavement failure along the F209 highway at Ado-Ekiti, Southwestern Nigeria. Construction and Building Materials. 2000; 14: 311- 315.

[5] Ofonime A, Aniekan E. Relationship between road pavement failures, engineering indices and underlying geology in a tropical environment. Global Journal of Geological Sciences. 2005; 4(2): 99 – 108.

[6] Akintorinwa OJ, Ojo JS, Olorunfemi MO. Appraisal of the causes of pavement failure along the Ilesa-Akure highway, Southwestern Nigeria using remotely sensed and geotechnical data. Ife Journal of Science. 2011; 13(1): 185-197.

[7] Osuolale OM, Oseni AA, Sanni IA. Investigation of highway pavement failure along Ibadan-Iseyin Road, Oyo State, Nigeria. International Journal of Engineering Research & Technology (IJERT). 2012; 1(8), 1-6.

[8] Etim RK, Eberemu AO, Osinubi K.J. Stabilization of black cotton soil with lime and iron ore tailings admixture. Journal of Transportation Geotechnics Elsevier. 2017; 10:85-95. http://dx.doi.org/10.1016/j.trgeo.2017.01.002

[9] Bassey OB, Attah IC, Ambrose EE, Etim RK. Correlation between CBR Values and Index Properties of Soils: A Case Study of Ibiono, Oron and Onna in Akwa Ibom State. Resources and Environment. 2017; 7(4): 94-102. http://dx.doi.org/10.5923/j.re.20170704.02

[10] Moses G, Etim RK, Sani JE, Nwude M. Desiccation effect of compacted tropical black clay treated with concrete waste. Leonardo Electronic Journal of Practices and Technologies. 2018; Issue 33: 69-88.

[11] Sani JE, Etim RK, Joseph A. Compaction behaviour of lateritic soil–calcium chloride mixtures. Geotechnical and Geological Engineering. Springer Nature Switzerland. 2019a; 37: 2343-2362. https://doi.org/10.1007/s10706-018-00760-6

[12] Sani JE, Yohanna P, Etim RK, Attah IC, Bayang, F. Unconfined compressive strength of compacted lateritic soil treated with selected admixtures for geotechnical applications. Nigerian Research Journal of Engineering and Environmental Sciences. 2019b; 4(2): 801-815.

[13] Etim RK, Attah IC, Eberemu AO, Yohanna P. Compaction behaviour of periwinkle shell ash treated lateritic soil for use as road sub-base construction material. Journal of GeoEngineering, Taiwan Geotechnical Society. 2019; 14(3): 179-190, http://dx.doi.org/10.6310/jog.201909_14(3).7

[14] Etim RK, Attah IC, Yohanna P. Experimental study on potential of oyster shell ash in structural strength improvement of lateritic soil for road construction. International Journal of Pavement Research Technology, Chinese Society of Pavement Engineering, Springer Nature Singapore. 2020. https://doi.org/10.1007/s42947-020-0290-y

[15] Attah IC, Agunwamba JC, Etim RK, Ogarekpe NM. Modelling and predicting of CBR values of lateritic soil treated with metakaolin for road material. ARPN Journal of Engineering and Applied Sciences. 2019; 14(20): 3606 – 3618.

[16] Moses G, Etim RK, Sani JE, Bobai YS. Geotechnical properties of crude oil incinerated lateritic soil for use in roadwork. FUW Trends in Science & Technology Journal, Federal University Wukari. 2019; 4(1): 69 – 74.

[17] Moses G, Etim RK, Sani JE, Nwude M. Desiccation-induced volumetric shrinkage characteristics of highly expansive tropical black clay treated with groundnut shell ash for barrier consideration. Civil and Environmental Research. 2019; 11(8): 58–74. https://doi.org/10.7176/CER/11-8-06

[18[Muench ST, Moomaw T. De-bonding of hot mix asphalt pavements in Washington State: An initial investigation. Technical report. Washington 146 State Department of Transportation, Office of Research & Library Services: Transportation Northwest Regional Center X (TransNow) 2008.

[19] Caro S, Masad E, Bhasin A, Little DN. Moisture susceptibility of asphalt mixtures, Part 1: mechanisms," International Journal of Pavement Engineering. 2008; (9): 81-98.

[20] Alhaji MM, Alhassan M. Effect of reclaimed asphalt pavement stabilization on the microstructure and strength of black cotton soil. International Journal of Technology. 2018; 9(4): 727–736.

[21] Ahmedzade P, Sengoz B. Evaluation of steel slag coarse aggregate in hot mix asphalt concrete. J Hazard Mater. 2009; 165:300–305.

[22] Uzun I, Terzi S. Evaluation of andesite waste as mineral filler in asphaltic concrete mixture. Constr Build Mater. 2012; 31:284–288.

[23] Akinleye MT, Tijani MA. Assessment of quality of asphalt concrete used in road construction in South West Nigeria. Nigerian Journal of Technology Development. 2017; 14(2): 51 – 54.

[24] Nigerian General Specifications, NGS: Roads and Bridges. Federal Ministry of Works, Abuja, Nigeria. 1997.

[25] Osunkunle A, Yusuf I, Ako T, Abolarin J. Assessment of engineering properties of asphaltic concrete produced in South Western Nigeria. Webs Journal of Science and Engineering Application. 2016; 5(1) 41-48.

[26] Obeta IN, Njoku JE. Durability of flexible pavements: A case study of South-Eastern Nigeria, Nigerian Journal of Technology. 2016; 35(2): 297-305.

[27] Alkawaaz NG, Qasim HA. Experimentally evaluation of durability characteristics for reclaimed local asphalt pavement mixtures. Imperial J Interdiscipl Res. 2016; 2(10).

[28] Erlingsson, S. Modelling of rutting development in pavement structures. Procedia-Social and Behavioral Sciences. 2012; 48: 321-330.

[29] Bala N, Napiah M, Kamaruddin I. Application of multivariable regression models for prediction of composite nanosilica/polymer asphalt mixture OBC. International Journal of GEOMATE. 2018; 14(45): 202-209. https://doi.org/10.21660/2018.45.94051

[30] Kim SH, Kim N. Development of performance prediction models in flexible pavement using regression analysis method. KSCE Journal of Civil Engineering. 2006; 10(2): 91–96.

[31] Laurinaviˇcius A, Oginskas R. Experimental research on the development of rutting in asphalt concrete pavements reinforced with geosynthetic materials. Journal of Civil Engineering and Management. 2006; 12(4): 311–317.

[32] Shukla PK, Das A. A re-visit to the development of fatigue and rutting equations used for asphalt pavement design. International Journal of Pavement Engineering, 2008; 9(5): 355–364.

[33] Asifur Rahman ASM, Mendez Larrain MM, Tarefder RA. Development of a nonlinear rutting model for asphalt concrete based on Weibull parameters. International Journal of Pavement Engineering. 2017; 1–10.

[34] Baldo N, Manthos E, Pasetto M. Analysis of the mechanical behaviour of asphalt concretes using artificial neural networks. Advances in Civil Engineering. Article ID 1650945, https://doi.org/10.1155/2018/1650945

[35] Igwe EA, Ayotamuno MJ, Okparanma RN. Road surface properties affecting rates of energy dissipation from vehicles. J Appl Energy. 2009; 86: 1692–1696.

[36] Agunwamba JC. 2007. Engineering Mathematical Analysis. De-Adroit Innovation, Enugu, Nigeria.Chap 16 and 17. ISBN 978-8137-08-3.

[37] Aboufoul M, Garcia A. Factors affecting hydraulic conductivity of asphalt mixture," Materials and Structures. 2017; 50, p. 116.

[38] Etim, R. K. Ekpo, D U. Ebong, UB, Usanga, I. N. (2021) Influence of periwinkle shell ash on the strength properties of cement-stabilized lateritic soil. International Journal of Pavement Research Technology, Chinese Society of Pavement Engineering, Springer Nature Singapore. https://doi.org/10.1007/s42947-021-00072-8

[39] Etim, R. K., Attah, I.C., Ekpo, D.U., Usanga, I.N. (2021) Evaluation on Stabilization Role of Lime and Cement in Expansive Black Clay - Oyster Shell Ash Composite. Transportation Infrastructure Geotechnology. https://doi.org/10.1007/s40515-021-00196-1

[40] Etim, R. K., Ekpo, D U. Etim, G.U., UB, Attah, I.C (2021) Evaluation of lateritic soil stabilized with lime and periwinkle shell ash (PSA) admixture bound for sustainable road materials. Innovative Infrastructure Solutions. https://doi.org/10.1007/s41062-021-00665-z

[41] Etim, R. K., Ekpo, D U., Attah, I.C. Onyelowe, K.C. (2021) Effect of micro sized quarry dust particle on the compaction and strength properties of cement stabilized lateritic soil. Cleaner Materials, https://doi.org/10.1016/j.clema.2021.100023

[42] Attah, I.C., Etim, R.K., Ekpo, D.U., Onyelowe, K.C. (2021) Understanding the impacts of binary additives on mechanical and morphological response of ameliorated soil for road infrastructures. Journal of King Saud University-Engineering Sciences, https://doi.org/110.1016/j.jksues.2021.12.001

[43] Yohanna, P., Etim, R.K., Ijimdiya, T.S., Osinubi, K.J., Buki, J.M. (2022) Reliability analysis of compaction characteristics of tropical black clay admixed with lime and iron ore-silica based dominant tailing. epitoanyag – Journal of Silicate Based and Composite Materials. Vol. 74 No.1; pp. 13-20. http://doi.org/10.14382/epitoanyag-jsbcm.2022.3

[44] Yohanna, P., Ibrahim, U.A and Etim, R. K. (2020) Compaction Behaviour of Black Cotton Soil Treated with Selected Admixtures: A Statistical Approach. Premier Journal of Engineering and Applied Sciences. Publication of Nigerian Society of Engineers, Ibadan Branch. Vol. 1, No. 1, pp. 35 – 44

[45] Yohanna, P., Kanyi, M. I., Etim, R. K., Eberemu, O. A., Osinubi, K. J. (2021) Experimental and Statistical Study on Black Cotton Soil Modified with Cement–Iron Ore Tailings. FUOYE Journal of Engineering and Technology (FUOYEJET), Vol. 6, Issue 1, http://dx.doi.org/10.46792/fuoyejet.vAiB.C

[46] Etim, R. K., Eberemu, A. O and Osinubi, K. J. (2014) Effect of Lime – Iron Ore Tailing Blend on the Expansive Behaviour of Black Cotton Soil. In: Proceeding of Nigeria Engineering Conference. Theme: Engineering and Technology for Economic Transformation. Faculty of Engineering, Ahmadu Bello University, Zaria, September 15-18, 2014. Zaria, Kaduna State. CR ROMs of Presentation; 2014: 864 – 874.

[47] Sani, J. E., Yohanna, P., Etim K. R., Osinubi, J. K. and Eberemu, O. A. (2017). Reliability Evaluation of Optimum Moisture Content of Tropical Black Clay Treated with Locust Bean Waste Ash as Road Pavement Sub-base Material. Geotechnical and Geological Engineering Springer. http://link.springer.com/article/10.1007/sl0706-017-0256-2

[48] Onyelowe, K.C., Bui Van, D (2018) Predicting strength behaviour of stabilized lateritic soil- ash matrix using regression model for hydraulically bound materials purposes, Int. J. Pavement Res. Technol. https://doi.org/10.1016/j.ijprt.2018.08.004

Ref.:

Etim, Roland Kufre – **Usanga**, Idorenyin Ndarake – **Ekpo**, David Ufot – **Attah**, Imoh Christopher: *Material characterization and statistical evaluation of properties of hot mix asphalt concrete (HMAC) used in wearing course of road pavement; Southern Nigeria*

Építőanyag – Journal of Silicate Based and Composite Materials, Vol. 74, No. 5 (2022), 196–205. p.

https://doi.org/10.14382/epitoanyag-jsbcm.2022.29

Üvegipari szakmai konferencia a Daniella Ipari Park Kft. Energocell hőszigetelő üveghabgyártó üzemében

2022. október 11.

A Szilikátipari Tudományos Egyesület Üveg Szakosztályának hagyományos őszi szakmai konferenciájára ezúttal a Daniella Ipari Park Kft. szíves közreműködésével a nemrég beüzemelt Energocell hőszigetelő üveghabgyártó üzemében került sor. A rendezvény előadásaiban kiemelt szerepet kaptak a 2022 – Az Üveg Éve aktuális eseményei, illetve a vendéglátó cég tevékenységének és legújabb üzemének bemutatása.

A 2022 - Az Üveg Éve az ENSZ dedikált, egy éven át tartó rendezvénye, melynek célja, hogy felhívja a társadalom és a döntéshozók figyelmét az üvegben rejlő lehetőségekre, a modern társadalomban betöltött, nélkülözhetetlen funkcióira, melyeket előrelátó tervezéssel fenntartható módon lehet előállítani.

A fenntarthatóságnak egyik fontos aspektusa az elsődleges nyersanyag-szükséglet csökkentése, másod-nyersanyagok minél nagyobb mértékű felhasználása a keletkező ipari melléktermékek, hulladékok hasznosítása révén. A megfelelő technológia és alapanyag-receptek kifejlesztésével környezetkímélőbb módon, a bányászott nyersanyagok mennyiségének csökkentésével, kevesebb energia felhasználásával állíthatunk elő termékeket. A Daniella Ipari Park Kft. terméke, az Energocell üveg-hab és annak gyártása eklatáns példái a tudatos, kör-forgásos gazdálkodásnak és a fenntartható nyersanyag gazdálkodásnak, melyhez kreatív és innovatív mérnöki-műszaki megoldásokra is láthattak a résztvevők példákat az előadásokat követő üzemlátogatás során.

A szakmai konferencia az értékes előadások mellett jó lehetőséget biztosított az ipari és akadémiai, kutatás – fejlesztési és felsőoktatási szakemberek részére együttműködési, fejlesztési lehetőségek megvitatására is.

A rendezvény szervezői, a Szilikátipari Tudományos Egyesület Üveg Szakosztálya, illetve a Daniella Ipari Park Kft. valamennyi érdeklődőnek ezúton is köszönik a részvételt. Remélik továbbá, hogy immár véglegesen visszatér a jelenléti szakmai rendezvények lehetősége, és jövő tavasszal a hagyományaink szerint folytatódhat egy hasonlóan sikeres szakmai konferenciával a találkozók sora.