Case study evaluation of selected binder course asphalt concrete used in road construction in Nigeria

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Abstract

This study evaluates asphalt concrete (binder course) being one of the components of flexible pavement to determine the quality grade of asphalt used in construction in line with the Nigeria General specification (NGS). Compacted binder course samples were collected from three selected asphalt plants in Akwa Ibom State and subjected to bitumen extraction, Marshall Stability and flow test. Characterization of materials was carried out in line with requisite standard and specification for binder course. Statistical data analysis tool (minitab and Microsoft excel 2013) was used to validate the relationship between bitumen content and other related variables. The results indicate that more than 95 % samples satisfied the requirement of Marshall Stability, flow and bitumen content, based on the NGS for roads. The results of multiple regression models and analysis of variance as well as the relationship between the experimental and predicted outcome of bitumen content indicate that stability and flow cannot be used in predicting the optimum bitumen content yields. Also, the relationship between bitumen content and other related Marshall variables show that these variables should be carefully monitored during Marshall Stability for optimum design. The scan electron microscopy results revealed voids in compacted specimen. This study has shown that microanalysis through SEM is significant and should be incorporated into pavement evaluations in addition to conventional material characterization and various physical and mechanical quality control tests.

Keywords: asphalt binder course, bitumen content, stability, flow, scan electron microscopy, statistical evaluations

Kulcsszavak: aszfalt kötőanyag réteg, bitumentartalom, stabilitás, folyás, pásztázó elektron-mikroszkópia, statisztikai kiértékelések

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1. Introduction

Road construction and infrastructure is one of the biggest capital investments of many countries world over. This is a critical sector which is generally known to automatically boost the economy of many countries. With the consistent public outcry in raising the infrastructural deficit in Nigeria, road construction is now in the exclusive list of government priority at all levels. Without a well-maintained road system, the transportation infrastructural needs of the public, businesses, industries and government cannot be met [1]. Road transportation provides vital links between spatially separated facilities which enables social contact and interaction between man and the environment [2]. However, premature failure and subsequent deteriorations of road pavement due to poor qualities of binder course amongst other factors have hampered the socio economic activities of many economies. Therefore, with regard to the paramount importance of road network in the economic development, safety and social cohesion of each country, it is important to continually assess the quality of materials that is used in road construction.

Asphaltic concrete is one of the vital materials in pavement construction. It is a composite material made up of aggregates, binder and filler materials which is commonly used in providing a stable surface area on highways of road surface, parking lots and runways of airport [3]. Asphalt plays a vital role in global transportation infrastructure and drives economic growth and social well-being in developed as well as developing countries [4]. An average asphalt pavement consists of the road structure above the formation level which include unbound and bituminous bond materials. This gives the pavement the ability to distribute the loads of traffic before it arrives at the formation level. About 95 % of roads in Nigeria are surfaced with asphalt concrete composite. Amongst other factors, bitumen content in this composite is one of the significant parameters that could affect the sustainability and durability of road sections. Binder course is one of the layers of pavement structure and its plays a very significant role in protecting the underlying layers (sub-base and subgrade) in the complete cross section of a road pavement structure. The quality of asphalt concrete for binder course in road structure depends on the bitumen content amongst other material quality and factors which is key to the durability and sustainability of the underlying sub base and sub grade layers.

Asphaltic concrete mix design and their engineering properties form an essential part for all asphaltic concrete mixture. An asphaltic concrete is designed, produced and placed in order to obtain desirable properties which include; stability, durability, flexibility, fatigue resistance, skid resistance, impermeability and workability. In Akwa Ibom State, huge investments have and still being made by government on the construction of new roads and rehabilitation of existing ones [5]. However, most of these roads are considered unsafe for vehicular movement, extend travel time due to premature development of potholes, cracks and various signs of pavement distresses. This situation has called for investigation on road pavement materials used in construction of roads in Akwa Ibom State. This is with the aim of ensuring that road pavements are in serviceable condition within its design life. The durability of a cross section of a road pavement is a function of the sub-structure material (sub-grade and sub-base). The reliability of these materials either in its natural or modified form might not be unconnected with some of their engineering behavior in terms of plasticity, CBR and UCS [6-20, 35-43]. Several studies have been conducted on the qualities of materials used in pavement construction and general assessment of infrastructural quality in Akwa Ibom State. Ilori [21] reported the suitability of naturally occurring aggregates as sub base and subgrade construction materials in Akwa Ibom State and concluded that 85 % of the sample materials satisfied the AASTHO and US Army criteria upon particle size distribution, plasticity index, liquid limit and California Bearing Ratio value. Similarly, Osunkunle et al. [22] presented that asphaltic concrete produced in southwestern Nigeria conform to the specifications of the Federal Ministry of Works and that the quality and quantity of bitumen and aggregates used for production were satisfactory. They went further to revealed that despite the strict adherence to specification standard, roads were subjected to severe pressure as a result of increased vehicular traffic which contribute to pavement failures. In conclusion, they recommended that regular laboratory analysis must be conducted to ensure that asphalt concrete produced conform to the acceptable standards. Akinleye and Tijani [23] also carried out a study to assess the quality of asphalt concrete used in south west Nigeria. They reported that the comprehensive assessment revealed non conformity of asphalt concrete samples to the Federal Ministry of Works specification. They further concluded that the use of poorly graded mineral aggregates, poor and inadequate bitumen content resulted in the mixture having poor stability, flow and excess voids. A considerable amount of literature has been published on the utilization of asphalt as a road pavement material. However, it seems little attention has been paid to Akwa Ibom state, because of the limited published report.

Consequently, it is important to investigate the quality of asphaltic concrete used in the construction sector so as to appraise the situation of incessant failure of flexible pavement as reported [22, 23]. Whilst there are various ranges of test associated with various sections of a road pavement, this study will only consider the testing of materials for binder course section of a road pavement. Based on hands-on practical data established from some of the tests, far reaching results have been obtained in specific areas. However, some of these outcomes have not been made available to public domain for purpose of scientific validation from the various findings. Thus the need to report such investigations as case study situation for Akwa Ibom state becomes necessary as it would reflect the true quality of binder course asphalt used in road construction as well as contribute to the existing report. Also, morphological investigation through scanning electron microscopy further gives impetus to the outcome of this study thus closing the gap and shortfall in previous study reported for case of wearing course asphalt in same region [34].

Various modelling techniques are used in predicting different factors or variable in asphaltic concrete. Wang et al. [24] predicted the stress of asphalt concrete using multiple linear regression. Bala et al. [25] proposed a model which yields good predicted results for optimum binder content using stability and flow results obtained from Marshall Stability results. Kim and Kim [26] used the regression analysis to develop a performance prediction model. Also, prediction models developed from properties of asphalts material was realized from well-built investigational outcome using statistical regression method [27 - 29]. Baldo et al. [30] used artificial neural networks (ANN) and predicted the numerical-mechanical behaviour of asphalt concretes for road pavement. Also, the use of simple statistical applications has become necessary to validate or appraise laboratory data in civil engineering [6 - 20]. Therefore, the use of multilinear regression model would be essential to evaluate large laboratory results obtained from stability test of binder asphaltic concrete. In the light of the foregoing, this paper present an overview of the simple multiple regression application carried out for selected asphalts concrete production plants in Akwa Ibom state, as part of evaluations study on Marshall Stability investigation and material characterisation for the production of asphaltic concrete bound for binder course level.

Developing effective predictive equations for any reasonable variable that offers a major role in Marshall Stability investigation are fundamental to the outcome of optimum design of asphaltic concrete. Although lack of adequate data or sample size has made it almost impossible to use conventional statistical modelling tools/package such as simple regression Kajner et al. [31]. However, the use of large sample size obtained from eliminating inconsistent results due to laboratory errors addresses the lack of adequate data or sample size which has made its almost impossible to use conventional statistical modelling tools/package. The trust of this study is based on the fact that larger data mining from variables in Marshall stability investigation was obtained within a longer space of time and the out of range results which are inconsistent due to experimental error were rejected in this study. Although simple linear regression is an assured solution used in a number of studies to coherently permits clear decision and proffer solutions, this study seeks to test the adequacy, robustness and usability of simple multiple linear regression in determination of optimum binder content.

2. Materials and methods

2.1 Materials

The bitumen, aggregate and asphaltic concrete for binder course were sourced from major three asphalt plant in Akwa Ibom state, Nigeria. Although the batch of production were based on satisfactory established optimum design that meet the requirement of asphaltic concrete according to NGS [32] was adopted by each of the production plant. The characterization of bitumen and aggregate materials was done to ascertain that quality according to specification was maintained throughout the study.

2.2 Methods

Samples of materials used in asphaltic concrete production were collected from three different asphalt plants during production and on information that they are for binder course. Preliminary investigation on bitumen (penetration and softening points tests) and aggregates (fine and coarse) used in each asphalt production was carried out. Asphaltic concrete was collected from three asphalt plants labelled as A, B, and C and their corresponding samples of binder course was labelled as sample 1 to 12. Samples was analyzed for bitumen extraction, sieve analysis, Marshal Stability and flow according to related standards (*Table 1*).

Test	Standard
Bitumen	
Penetration test	AASHTO D T 49
Softening point	ASTM D36-95
Flash point	AASHTO D T-48
Aggregates/Asphalt Concrete	
Aggregates (Fine and coarse)	ASTM C127/C128
Specific gravity (bituminous mixture)	ASTM 2041
Los Angeles Abrasion test	ASTM C131/ EN 1097-8
Flakiness index	EN 933-3
Aggregate crushing value ACV	BS 812-114
Bitumen extraction	ASTM D2172
Marshall stability	ASTM D1669
Sieve analysis	ASTM C136

Table 1 Test and standard of testing used
1. táblázat Az alkalmazott vizsgálati szabvány

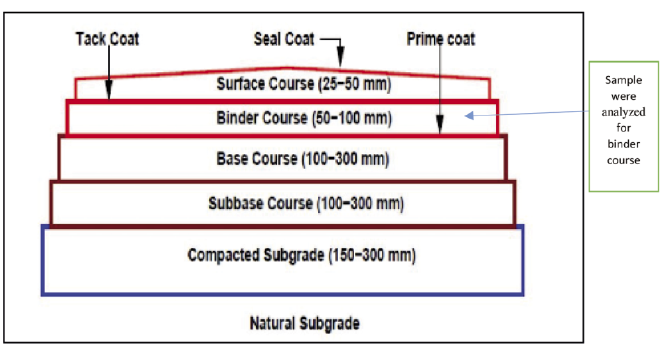

Fig. 1 Typical layers of conventional flexible pavement includes seal coat, surface or wearing course, tack coat, binder course, prime coat, base course, sub-base course, compacted subgrade, and natural subgrade
1. ábra A hagyományos rugalmas burkolat tipikus rétegei közé tartozik a tömítőréteg, a felület vagy a kopóréteg, a tapadóréteg, a kötőanyagréteg, az alapbevonat, az alapréteg, az aljzatréteg, a tömörített aljzat és a természetes aljzat

This test was carried out for twelve-month duration to span throughout a calendar year of both wet and dry weather conditions. The minimum of three samples of binder course asphalt were adopted. The result is collated and compared with general specifications for roads and bridges from Federal Ministry of Works and Housing to make necessary recommendations. Tests results (Marshall Stability) was confirmed for consistency based on specifications of NGS [32]. The various units of a flexible pavement of a road structure is shown by the cross section of *Fig. 1*. The bottom structure is the natural formation ground level also known as the natural subgrade while the top most layer is called the wearing course or surface course with seal coat followed by the second from top (binder course).

2.2.1 Formulation of regression model

The simple multiple study focused on the development of a model to predict the bitumen/binder content (optimum) in asphalt concrete for binder course pavements. The data used in the analysis were obtained from the laboratory study of several batches of asphaltic concrete production for the various selected companies. The guidelines of Agunwamba [33] were followed in formulation of regression models and with strict adherence to the principle of asphalt mix design. The bitumen content in an asphaltic concrete is usually an intricate component for optimum and satisfactory design of asphalt concrete. Bitumen content is therefore modelled for the selected asphalt plants denoted by A, B and C. Data used in this study were result of laboratory study obtained from several batches of asphalt production from the said plant. In this study, asphalt produced for binder course of a road pavement is assumed to meet Marshall Stability optimum mix design according to NGS [32] specification. Throughout the study, the condition of the laboratory was kept and sustained at room temperature. All other factors were assumed unchanged with regard to the study in consideration. The behaviours of bitumen content (optimum) in asphaltic concrete for the various asphalt plant were then modelled using the concept of multiple linear regression association with twelve data points. The twelve data point is a function of minimum of three average values that were observed to be very close to each other.

2.2.2 Bitumen content regression model

Independent variable (Y) identified as optimum bitumen content (B_{opt}) was achieved based on identified independent variables x_1 and x_2 as stability (S) and flow (F), respectively. The mode of compaction and other associated conditions of laboratory are kept constant. The general formula for multilinear regression is presented as:

$$Y = a + bx_{1(i)} + Cx_{2(i)} + \varepsilon \quad (1)$$

Where $Y = B_{opt}$; $x_{1(i)}$ =stability, S; $x_{2(i)}$ = flow, F;

a, b and c are constants called regression constants. i = 1, 2, 3,...n data points for asphalt plants A, B and C respectively. ε = zero random erratic error due to level of accuracy with which the laboratory investigation was achieved. *Eq. 1* is the linear form for selected three variables associated with the prerequisite needed for quality and sustainable pavement structure based on accumulated laboratory study. For the set of populated data points results and reducing the sum of least square results, the constant as well as coefficient of regression (a, b and c) are determined using Microsoft 2013 excel tools.

This implies that $B_{opt} = a + bF_{(i)} + cS_{(i)}$; i = 1,2,3,…,n (2)

Additional statistical tool was deployed to check the adequacy of the models. The experimented and predicted responses from linear model were paired and then subjected to ANOVA (single factor).

3. Results and discussion

3.1 Characterization of materials used

Characterization of materials used in this study is shown in *Table 2* for bitumen. The penetration test of bitumen at 25°C for the three samples clearly show that all samples had penetration above 60/70 penetration value allowable in FMW [32] general specification for road construction in tropical climate like Akwa Ibom State.

Test	A	B	C	Specified limit by NGS
Penetration test	60	62	64	60-70 at 25°C
Specific gravity	1.01	1.02	1.01	1.01-1.05 at 25°C
Softening point	50°C	49°C	48°C	48-50°C
Flash point	254	253	252	250°C

Table 2 Characteristic properties of bitumen
2. táblázat A bitumen jellemző tulajdonságai

Aggregate properties	Asphalts concrete site D	E	G	Specified limits NGS
Gs (Coarse aggregate)	2.68	2.68	2.68	-
Gs (fine aggregate)	2.64	2.67	2.67	-
Average % passing 75 um sieve	93	94	95	≥ 75 %
Los Angeles Abrasion test, %	16	17	21	≤ 25 %
Aggregate crushing value ACV, %	21	22	22.5	≤ 30 %
Flakiness index %	19	21	20	≤ 35 %

Table 3 Properties of aggregate used for asphalt production
3. táblázat Az aszfaltgyártáshoz használt adalékanyagok tulajdonságai

The test measures the hardness or consistency of bituminous material. The outcomes of this test confirms that the bitumen is soft which may be accredited to the existence of dilutants. During asphalt production, bitumen is heated to reduce it viscosity, hence the presence of dilutants will vaporize thus reducing the amount of bitumen content in the mixture and may subsequently leads to raveling which will result in premature failure of pavement. The result of softening point values for the three samples. The test is carried out to ascertain the temperature at which the bituminous materials attain a certain viscosity level. Bitumen softening point should be higher than the hottest day temperature of the study area otherwise bitumen may sufficiently soften and result in bleeding and development of ruts. In the study area, the average hottest temperature is about 26.7 °C and the softening point for all the three samples were above 48 °C. The conformity of the softening values with the standard specification indicate an asphalt concrete with increase resistance to permanent deformation (the standard). The ductility test of bitumen samples indicates a mean ductility value that is above 100 cm. The minimum recommended value specified by general specification for roads and bridges is 100 cm. It is important that bituminous material forms ductile film around the aggregates which serve as a binder. Bitumen without sufficient ductility, renders pervious pavement surface and leads to development of cracks. The properties of aggregates tested for the three selected sites as presented in *Table 3* indicate satisfactory limit as asphaltic road material specified in FMW general specification [32].

3.2 Sieve analysis

The gradation of the aggregate sizes for the three samples are obtainable in *Fig. 2*. However, for samples A, B and sample C obtained from the three asphalt plants show that the three specimens lie on a smooth curve within the envelope. Poor particle size distribution of aggregates utilized in asphalt mixture plays a major role in the stability and stiffness of the binder layer.

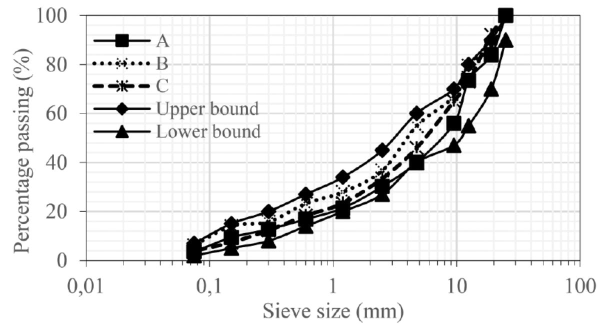

Fig. 2 Typical gradation of aggregates from binder course from site A, B and C
2. ábra Az A, B és C helyszínről származó kötőanyagból származó aggregátumok tipikus osztályozása

3.3 Asphalt concrete properties for binder course

The properties of asphalt concrete phase of binder course quality that meet the basic requirement and purpose for the region of study is controlled and tied to the relevant limit as per Nigeria general specification shown in *Table 4*. The results of the selected asphalt plants A, B and C are presented in *Table 5*. The results of each samples revealed the following engineering properties of asphalt; marshal stability (S), flow (F), bitumen content (BIT), voids in total mixture (VIM) and voids filled with bitumen (VFB). It is expected that asphalt concrete from the three asphalt plant can withstand traffic load without getting cracked. The results also suggest that failure in pavement structure which have been often said to be associated with the quality of asphaltic concrete may not be entirely accurate as it were. While the writer notes that quality of asphalt could be compromised for financial gains and inducement, poor material handling/ preparation etc., it is also relevant to note that failure in service could be due to poor and or inefficient compaction of sub grade and subbase structure, excessive wheel load greater than expected traffic design, poor drainage condition etc. This suggests why continued research into deficient soil improvement for subgrade and sub-base structure of road construction and hydraulic bound material are reported [13 – 20, 35-43] and are continuously given attention. The results in this study indicate that the bitumen content ranged from 4.50 to 5.40, 4.80 to 5.60 and 4.50 to 5.20 for asphalts A, B and C, respectively. Also, the stability and flow result were observed to be satisfactory and in line with the quality of asphalt specified in NGS [32] for binder course layer.

Properties	Standards as per NGS
Bitumen content, BIT (%)	4.5 - 6.5
Stability, S (kN)	≥3.5 KN
Flow, F (mm)	2 - 6
Voids in total mix, VIM (%)	3 -8
Voids filled with bitumen, VFB (%)	65 -72

Table 4 Standard of asphalt concrete of binder course
4. táblázat Kötőanyagréteg aszfaltbeton szabványa

Specimen (binder course)	BIT (%)	VIM (%)	VMA (%)	VFB (%)	S (kN)	F (mm)
A1	5.40	3.18	16.11	66.02	14.62	3.18
A2	5.40	3.24	16.18	65.68	14.49	3.24
A3	4.90	3.65	16.22	65.33	16.10	3.65
A4	5.00	3.41	16.37	65.11	15.24	3.41
A5	5.40	3.22	16.63	66.13	14.44	3.22
A6	4.70	3.82	16.33	64.95	17.79	3.82
A7	4.90	3.38	16.26	63.22	15.08	3.38
A8	4.50	3.80	15.84	65.45	18.38	3.80
A9	5.20	3.27	15.92	64.00	14.70	3.27
A10	4.80	3.36	16.03	62.27	15.37	3.36
A11	5.30	3.35	16.14	65.67	14.78	3.35
A12	4.60	4.05	16.44	66.19	18.08	4.05
B1	5.60	4.92	11.48	66.32	16.15	4.92
B2	5.80	4.57	11.48	66.83	15.62	4.57
B3	5.40	4.51	15.21	70.50	17.60	4.51
B4	5.50	4.11	16.15	70.17	15.43	4.11
B5	5.20	4.26	15.09	66.71	15.03	4.26
B6	4.90	4.62	16.22	65.78	14.86	4.62
B7	5.10	4.66	15.81	70.29	14.97	4.66
B8	4.90	4.52	15.51	65.23	14.81	4.52
B9	4.80	4.86	15.66	70.66	14.73	4.86
B10	5.30	4.07	15.77	66.82	15.24	4.07
B11	5.10	4.72	16.48	71.51	14.95	4.72
B12	5.30	4.14	16.60	69.67	15.24	4.14
C1	4.80	2.90	16.07	65.05	14.95	2.90
C2	5.10	3.10	16.41	67.47	15.24	3.10
C3	4.60	3.20	16.78	65.24	14.65	3.20
C4	4.70	2.70	16.33	63.99	14.76	2.70
C5	4.50	3.15	16.67	63.43	14.49	3.15
C6	5.00	3.18	16.26	66.04	15.43	3.18
C7	4.90	3.34	16.82	64.66	15.19	3.34
C8	5.20	3.52	16.22	65.32	15.51	3.52
C9	4.80	3.16	16.74	63.17	15.03	3.16
C10	5.20	2.95	16.07	67.95	15.43	2.95
C11	4.90	3.45	17.56	65.27	15.19	3.45
C12	4.80	3.51	16.82	62.63	14.97	3.51

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=stability, F=Flow

Table 5 Analysis of asphalt concrete (binder course)
5. táblázat Az aszfaltbeton elemzése (kötőszerkezet)

3.4 Morphological properties of binder course asphalt

The morphological structure of selected batch of binder course asphalt were studied using scan electron microscope. Test specimens for SEM was obtained from compacted asphalt. Scan electron images evaluated from selected specimen A1, A4 and A9 of production plant A show a clear morphology of aggregates with bitumen coated on all particle sizes (*Fig. 3a-c*). Similarly, morphology of selected specimen B1, B4 and B9 of production plant B revealed aggregates and other constituent material are well batched such that aggregates are uniformly coated in the bituminous mix that show a relative dense structure (*Fig 4a-c*).

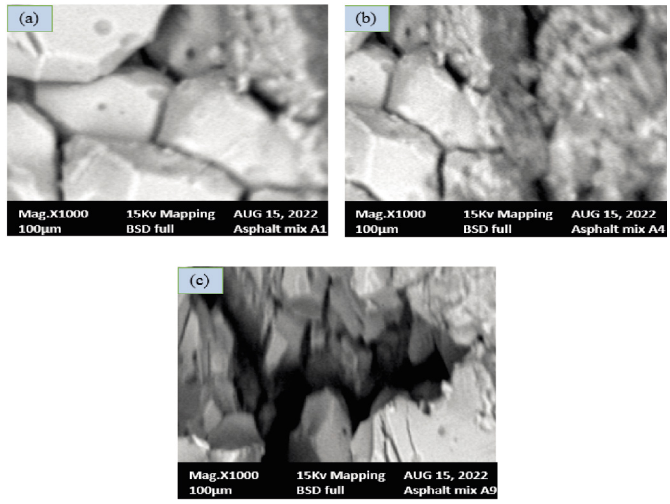

Fig. 3 Structural morphology of asphalt concrete collected from selected of asphalt plant A of: (a) A1, (b) A4 and (c) A9, batch productions
3. ábra Az A aszfaltüzemből gyűjtött aszfaltbeton szerkezeti morfológiája: a) A1, b) A4 és c) A9 gyártásnál

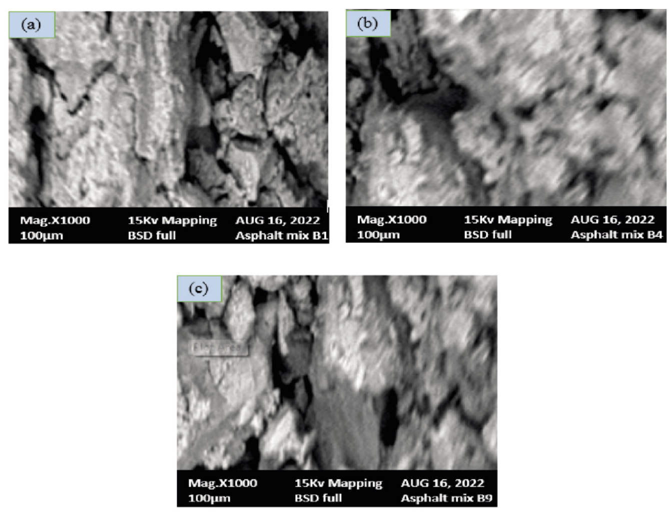

Fig. 4 Structural morphology of asphalt concrete collected from selected of asphalt plant B of: (a) B1, (b) B4 and (c) B9, batch productions
4. ábra A B aszfaltüzemből gyűjtött aszfaltbeton szerkezeti morfológiája: a) B1, b) B4 és c) B9 gyártásnál

Similar morphology is observed for selected specimen C1, C4 and C9 of production plant C (*Fig. 5a-c*). However, it is obvious that insignificant pore spaces were observed in all structures (A, B and C). This might not be unconnected with inadequate compaction of specimen. It can said that, the micrograph has clearly exposed the inefficiency of poor/faulty mechanical roller used by contractors and or poor placement and compaction protocol of materials. This scenario if not checked can eventually led to moisture percolation and consequent failure of other layers and collapse of the entire pavement. This study has further shown that microanalysis through SEM of high resolution configuration and other microanalysis should be incorporated into pavement quality control in addition to conventional material characterization and sundry physical and mechanical quality control tests.

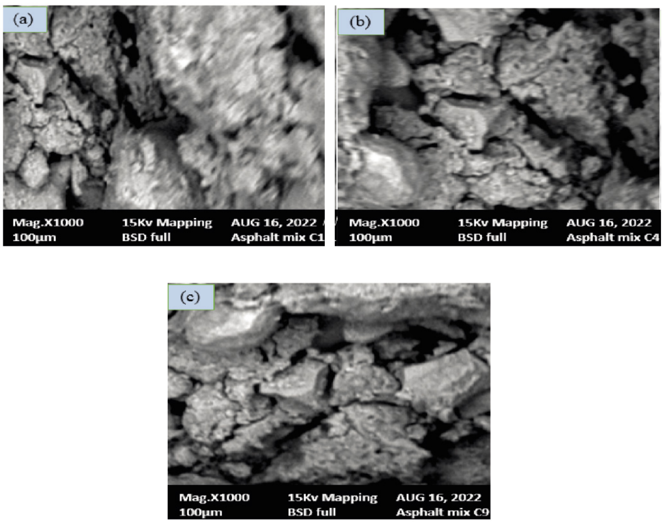

Fig. 5 Structural morphology of asphalt concrete collected from selected of asphalt plant C of: (a) C1, (b) C4 and (c) C9, batch productions
5. ábra A C aszfaltüzemből gyűjtött aszfaltbeton szerkezeti morfológiája: a) C1, b) C4 és c) C9 gyártásnál

3.5 Regression statistics

The results of simple multiple linear regression for optimum binder content (independent variable) on bitumen extraction test for binder and wearing course specimens from the three asphalts plants are shown in *Eq. 1* to *3*. The linear relation between the laboratory and predicted values did not show adequacy as R-squared were less than 0.95 (*Fig. 6*). Non-linear relationship could prove better although that is not considered in this study.

$$B_{opt.A} = 8.181 - 0.1723S_A - 0.1319F_A \quad (3)$$
$$B_{opt.B} = 2.941 + 0.2198S_B - 0.2405F_B \quad (4)$$
$$B_{opt.C} = -5.114 + 0.6829S_c - 0.0947F_c \quad (5)$$

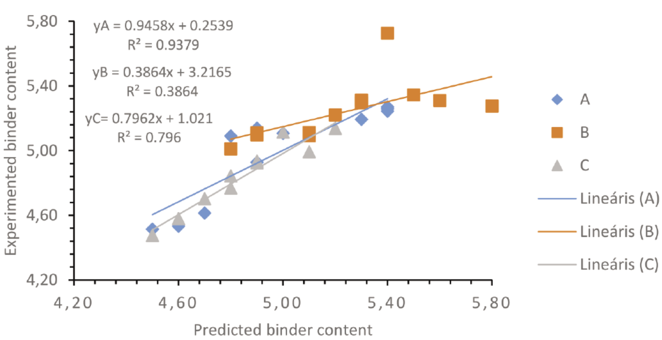

Fig. 6 Relationship between predicted and experimented binder content
6. ábra A várható és a kísérleti kötőanyag-tartalom közötti kapcsolat

Sample description	Y_{exp}	Y_{pred}	Abs. error	Percentage error
A1	5.40	5.24	0.0290	2.90
A2	5.40	5.26	0.0262	2.62
A3	4.90	4.93	0.0055	0.55
A4	5.00	5.11	0.0213	2.13
A5	5.40	5.27	0.0240	2.40
A6	4.70	4.61	0.0184	1.84
A7	4.90	5.14	0.0486	4.86
A8	4.50	4.51	0.0032	0.32
A9	5.20	5.22	0.0034	0.34
A10	4.80	5.09	0.0604	6.04
A11	5.30	5.19	0.0202	2.02
A12	4.60	4.53	0.0148	1.48
B1	5.60	5.31	0.0521	5.21
B2	5.80	5.27	0.0906	9.06
B3	5.40	5.73	0.0603	6.03
B4	5.50	5.34	0.0284	2.84
B5	5.20	5.22	0.0037	0.37
B6	4.90	5.10	0.0403	4.03
B7	5.10	5.11	0.0022	0.22
B8	4.90	5.11	0.0428	4.28
B9	4.80	5.01	0.0438	4.38
B10	5.30	5.31	0.0023	0.23
B11	5.10	5.09	0.0018	0.18
B12	5.30	5.30	0.0009	0.09
C1	4.60	4.58	0.0044	0.44
C2	5.10	4.99	0.0212	2.12
C3	4.60	4.58	0.0044	0.44
C4	4.70	4.70	0.0004	0.04
C5	4.50	4.48	0.0055	0.55
C6	5.00	5.11	0.0227	2.27
C7	4.90	4.93	0.0071	0.71
C8	5.20	5.14	0.0123	1.23
C9	4.80	4.84	0.0089	0.89
C10	5.20	5.14	0.0124	1.24
C11	4.90	4.92	0.0050	0.50
C12	4.80	4.77	0.0065	0.65

Table 6 Predicted and measured binder content values
6. táblázat A kötőanyag-tartalom előrejelzett értékei és mért értékei

The experimented results and predicted responses of optimum bitumen content shown in *Table 6* indicate that error ranged from 0.32 to 6.04, 0.09 to 9.06 and 0.04 to 2.12 for A, B and C, respectively. Further statistical tool is set up to check the adequacy of the models. The variables in experimented and predicted results are paired and then subjected to t-test (paired two sample for means) and ANOVA (single factor). Two conditions hypothesis namely; null and alternative hypothesis were used to interpret the t-test and single factor ANOVA. The null hypothesis states that there is no significant difference between the experimental results and predicted outcome of optimum binder content. Similarly, the alternative hypothesis is the reverse of the null hypothesis and of course implies that there is a significant difference between the experimental test and predicted outcome of optimum binder content results, which does not reflect a good prediction tool

Anova: Single Factor						
Summary						
Groups	Count	Sum	Average	Variance		
Yexp	12	60.1	5.008333	0.106288		
Ypred.	12	60.10405	5.008671	0.084644		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6.83E-07	1	6.83E-07	7.16E-06	0.997889	4.301
Within Groups	2.100255	22	0.095466			
Total	2.100256	23				

Table 7 Analysis of variance: Single factor for A
7. táblázat Varianciaelemzés A esetén

Anova: Single Factor						
Summary						
Groups	Count	Sum	Average	Variance		
Yexp	12	62.9	5.241667	0.091742		
Ypred.	12	62.89899037	5.241583	0.035445		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.25E-08	1	4.25E-08	6.68E-07	0.999355	4.30095
Within Groups	1.399062	22	0.063594			
Total	1.399062	23				

Table 8 Analysis of variance: Single factor for B
8. táblázat Varianciaelemzés B esetén

Anova: Single Factor						
Summary						
Groups	Count	Sum	Average	Variance		
Yexp	12	58.3	4.858333	0.055379		
Ypred.	12	58.18428	4.84869	0.052812		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.000558	1	0.000558	0.010314	0.920026	4.30095
Within Groups	1.190102	22	0.054096			
Total	1.19066	23				

Table 9 Analysis of variance: Single factor for C
9. táblázat Varianciaelemzés C esetén

However, from the anova results on the experimental and predicted results of A (*Table 7*), if F cal > F crit, then the model is adequate and significat in prediction of dependent variable. Consequently, the result has shown that F cal = 7.16E-06 and F crit = 4.301 thus F crit > F cal. Which indicates that the difference between the observed results and the model outcome values was not significant and cannot be considered effiecient or effective. Hence the model can be said to be inadequate for use in predicting the binder content for an optimum asphalt design mixture. Similarly, the results of B1 to B12 and C1 to C12 (*Table 6*) and corroborated with ANOVA (*Table 8* and *9*) follow the same trend as inadequacy is achieved. The implication of this study lies in the fact that multiple linear regression model cannot be used in prediction of optimum binder content for binder course grade of asphalt.

3.6 Correlation statistics

The results of correlation statistics with their respective p-values are presented in *Table 10-15*. Correlation statistic results for binder and wearing courses for the respective asphalt plants considered in this study were analyzed based on significant variables that were obtained during Marshall Stability investigation. These variables are BIT, VIM, VMA, VFB, S, and F representing bitumen content in total weight of mix, void in the mix, and void in total mix dry aggregate, void filled with bitumen, stability and Flow, respectively. It was observed that that BIT for site A, B and C which were correlated with (VIM, VMA, VFB, S, and F) shows changing correlations. For A, high negative values correlations were observed between BIT and VIM (-0.863; $P < 0.05$); S (-0.892; $P < 0.05$); F (-0.863; $P < 0.05$) while low correlations were observed between BIT and VMA (0.152; $P>0.05$) and VFB (0.259; $P > 0.05$) (See *Table 10*). For site B, varying correlations were observed between BIT and VIM (-0.214; $P > 0.05$); VMA (-0.676; $P < 0.05$) VFB (0.067; $P>0.05$); S (0.557; $P>0.05$) and F (-0.214; $P>0.05$) (See *Table 11*). And lastly for C, the correlations of BIT and VIM (0.189; $P>0.05$); VMA (-0.353; $P>0.05$); VFB (0.699; $P < 0.05$); S (0.960; $P < 0.05$) and F (0.189; $P>0.05$) is presented in *Table 12*. Detailed P-values results are shown in *Tables 13, 14* and *15*. The outcome of this analysis shows VIM, S and F significantly influence the BIT of site A, VIM for site B and VFB and S for site C. Therefore, these variables must be strictly monitored so as to achieve the best optimum bitumen content for design of asphalt concrete.

	BIT	VIM	VMA	VFB	S	F
BIT	1					
VIM	-0.863	1				
VMA	0.152	0.091	1			
VFB	0.259	0.188	0.377	1		
S	-0.892	0.957	-0.067	0.152	1	
F	-0.863	1	0.091	0.188	0.957	1

Table 10 Pearson correlation matrix for bitumen content; site A
10. táblázat Pearson korrelációs mátrix a bitumentartalomra vonatkozóan; A

	BIT	VIM	VMA	VFB	S	F
BIT	1					
VIM	-0.214	1				
VMA	-0.676	-0.400	1			
VFB	-0.067	0.055	0.428	1		
S	0.577	0.028	-0.367	0.148	1	
F	-0.214	1	-0.400	0.055	0.028	1

Table 11 Pearson correlation matrix for bitumen content; site B
11. táblázat Pearson korrelációs mátrix a bitumentartalomra vonatkozóan; B

	BIT	VIM	VMA	VFB	S	F
BIT	1					
VIM	0.189	1				
VMA	-0.353	0.553	1			
VFB	0.699	-0.217	-0.385	1		
S	0.960	0.299	-0.243	0.596	1	
F	0.189	1	0.553	-0.217	0.299	1

Table 12 Pearson correlation matrix for bitumen content; site C
12. táblázat Pearson korrelációs mátrix a bitumentartalomra vonatkozóan; C

	BIT	VIM	VMA	VFB	S	F
BIT	0					
VIM	0.000	0				
VMA	0.636	0.779	0			
VFB	0.417	0.558	0.227	0		
S	0.000	0.000	0.835	0.637	0	
F	0.000	0.000	0.779	0.558	0.000	0

Table 13 P-values (Pearson) for bitumen content; site A
13. táblázat P-értékek (Pearson) a bitumentartalomra; A

	BIT	VIM	VMA	VFB	S	F
BIT	0					
VIM	0.505	0				
VMA	0.016	0.198	0			
VFB	0.835	0.866	0.165	0		
S	0.049	0.931	0.240	0.646	0	
F	0.505	0.000	0.198	0.866	0.931	0

Table 14 P-values (Pearson) for bitumen content; site B
14. táblázat P-értékek (Pearson) a bitumentartalomra; B

	BIT	VIM	VMA	VFB	S	F
BIT	0					
VIM	0.556	0				
VMA	0.260	0.062	0			
VFB	0.011	0.497	0.216	0		
S	0.000	0.346	0.446	0.041	0	
F	0.556	0.000	0.062	0.497	0.346	0

Table 15 P-values (Pearson) for bitumen content; site C
15. táblázat P-értékek (Pearson) a bitumentartalomra; C

4. Conclusions

The study on analysis of binder course asphalt grade used in pavement construction clearly revealed that asphalt concrete from all the asphalt plants met the requirements for bitumen content, stability and flow when compared to requirements of NGS for roads and bridges. The aggregates gradation obtained from the study asphalt locations are well graded and falls within the grading envelope. The results of bitumen penetration, softening point and ductility tests were all satisfactory. The stability and flow results were satisfactory and within the acceptable quality control boundary for acceptability in line with NGS. This study has shown that microanalysis through SEM can be incorporated into pavement evaluations in addition to conventional material characterization and various physical and mechanical quality control tests. Also, there should be strict supervision of laying temperature of asphalt as well as the compaction temperature. Asphalt compaction thickness must conform to design provision and asphalt pavement surface should be subjected to adequate drainage condition to avoid failure cause by ingress of moisture. The study has shown that stability and flow not efficient as independent variables in prediction of optimum bitumen content for binder course asphalt concrete. The study recommends that extensive data mining from several asphalt plants not covered in this study be carried out in future work and a general predicting model developed and validated using robust statistical tool and or smart optimization techniques. Regardless of the assuring solution of simple multiple linear regression in a number of studies which in most cases clearly permits strong decision, this study confirmed an hitherto establish conventional result in asphalt mix design principle that optimum bitumen content cannot be derived by multiple linear regression of independent mechanical properties of flow and stability.

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