INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 14 NO. 1 (2023) 328-336

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Comparative Evaluation of the Engineering Properties of Asphaltic Concrete from Selected Asphalt Plants in Southwestern Nigeria for Road Construction

Samson Olukayode Olopade[1*], Adeyemi Oluwaseun Adeboje[2], Adewale Olukayode Olutaiwo[2], Adekunle Adedapo Obisanya[3]

[1]Department of Civil Engineering,
Yaba College of Technology, Lagos, NIGERIA

[2]Department of Civil and Environmental Engineering,
University of Lagos, Lagos, NIGERIA

[3]Department of Chemical Engineering,
Yaba College of Technology, Lagos, NIGERIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2023.14.01.030
Received 22 October 2022; Accepted 08 January 2023; Available online 14 February 2023

Abstract: In this study, the engineering properties of asphaltic concrete from selected asphalt plants in Southwestern Nigeria for road construction were sampled for three months, analysed and compared with regulatory body specifications. The penetration test, Ductility test, Marshall Stability and flow tests results indicated good conformity to the regulatory specification by all the plants with JBN exhibiting highest range value while LSPWC has the least. Also, asphalt samples from all the plants passed the Ring ball and softening point test with Julius Berger Nigeria having highest value between 53.5-53.7 while SEQUOIA has the least with 50-50.2 when compared to standard value 47-56. For bitumen content tests with 5-8% Specification, ESPRO failed with 3.9-4.8, LSPWC show inconsistence result of 3.9-5.6, SEQUOIA had the highest between 6.4-7.0, while CCECC and JBN conform to specification. The density-void ratio and particle size specification were met by only JBN with major deviation recorded from LSPWC. The result indicated JBN is the only company that satisfy all the engineering properties specification while others exhibit inconsistency in aggregates proportion thereby making the asphalt concrete a possible cause for pavement failure in Southwest Nigeria.

Keywords: Asphalt concrete, bitumen, ring and ball softening point test, extraction test, marshall stability and flow, density void ratio analysis

1. Introduction

Asphalt can either be obtained in nature or manufactured in the refinery [1]. Asphalt concrete is a composite material which contains asphaltic cement and mineral aggregates bound together. It can be utilized for road surfacing, parking lots and airports pavement [2]. "Bitumen is a mixture of hydrocarbons of natural or pyrogenous origin, or combinations of both, frequently accompanied by their non-metallic derivatives, which may be gaseous, liquid, semi-solid or solid, and which are completely soluble in carbon disulphide (CS2)" [3].

**Corresponding author: olukayode.olopade@yabatech.edu.ng*

Asphalt concrete is majorly used in Nigeria for road surfacing. Some used or recycled minerals can be reused as aggregates in asphalt-cement concrete mixture [4]. The characteristics of the asphalt constituent materials play a major role in the determination of the adequacy; structural stability and functionality of the resulting road pavement [5]. Asphalt concrete performance largely depends on the properties of the filler, aggregates and asphalt cement used for the production of the asphalt concrete [6].

Hot mix asphalt concrete (HMA or HMAC) is produced from the mixture of asphalt cement heated to desired consistency and dried aggregates (with moisture completely removed) to form asphaltic concrete. The mixing, placing and compacting of the HMA or HMAC is done at high temperature [7]. Though the asphalt cement is usually considered as the principal binder in the asphaltic concrete mix, the combination or blending of the asphaltic cement and filler mineral gives the binding matrix which holds the mineral aggregates together in the asphalt concrete mass [8] Engineering design is done to stipulate the specifications or minimum requirements that has to be met for each constituent material of an engineering component, in order to achieve a composite material which will give adequate properties for desired results [9]. The practice in civil engineering infrastructural development is to ensure that the current needs and the future needs of the populace are incorporated into the design and construction of facilities [10]. Adequate evaluation of and sufficient information on civil engineering works are essential for the achievement of quality assurance and sustainable construction [9, 10].

Quality control ensures adherence to standards and requirements of the specification(s) in the production of hot mix asphalt. It also encompasses all activities in the asphalt production such as mix design, material testing, sampling and acceptance of the asphalt concrete produced [11]. Quality control of asphalt mixes also provides for the assurance that materials and methods adopted in the production of the asphalt concrete will not only be adequate but also produce asphalt concrete which can withstand the envisaged applied load and last long, without failing [11, 12]. Quality control addresses the production and placement of asphalt for road construction works in order to determine when an operation has gone out of control and to respond to it and correct the irregularities [13, 14].
Asphalt concrete is a heterogeneous composite material with multi-phase microstructure having aggregates, air-voids and asphalt binder as its constituent materials [15]. Flat or round aggregate type requires more fine aggregates and binder content to attain full compaction, however, the resulting asphalt concrete tends to be slippery when the road pavement becomes wet [15, 16].

Many Nigerian roads are ravaged with infiltration or percolation of water from rain or other sources, improper slopping of the roadway surface (from crown to the side edges) and unavailability or inadequacy of drainage, among other factors [17–19]. The road surface can be hampered by weathering action, heat or rain, poor ground conditions, poor or inadequate drainage, inadequate clearance after construction and poor maintenance[17, 19–21].
Many Nigerian roads fail because they carry loads that are heavier than their designed load [20, 22]. This may either be due to inadequate integration of the traffic volume data in the original pavement design of the road or as a result of developments which have caused great increase in the traffic loading on such roads beyond the envisaged traffic volume[23]. Proper evaluation of the structural design of the road pavement is essentially important in the improvement of roads; and the road surface should be properly maintained, repaired or reconstructed after adequate evaluation of the road pavement layers [24–27].

Therefore, it is important to investigate asphalt cement from different sources used for the construction, repair or reconstruction of roads in southwestern parts of Nigeria in order to determine their suitability for intended purpose(s) and to also devise a means of improving the engineering properties of the asphalt mixtures for the achievement of adequate asphalt cement concrete mixture for road construction.

2. Materials and Methods

2.1 Sample Collection

Asphaltic concrete samples were collected from five (5) different asphalt plants in the southwestern part of Nigeria. The asphalt plants were China Civil Engineering Construction Corporation (CCECC), Mowe, Ogun State (latitude 6.8110^{O}N, longitude 3.4370^{O}E); ESPRO Asphalt Plant, Wasimi, Osun State (latitude 7.4166^{O}N, longitude 4.2166^{O}E); Julius Berger Nigeria (JBN) limited, Shagamu, Ogun State (latitude 6.8832^{O}N, longitude 3.5783^{O}E); Lagos State Public Works Corporation, (LSPWC), Ojodu-Berger, Lagos State (latitude 6.6396^{O}N, longitude 3.3684^{O}E) and Sequoia Asphalt Plant, Ibafo, Ogun State (latitude 6.7500^{O}N, longitude 3.4166^{O}E). Laboratory experiments conducted to determine the engineering properties of the asphaltic concrete samples were conducted in the Asphalt laboratory of the Civil and Environmental Engineering, University of Lagos, Lagos State, Nigeria (latitude 6.5151^{O}N, longitude 3.3886^{O}E).

2.2 Methods

The laboratory tests performed under the Marshall method of mix design include; Bulk density test, Marshall Stability and flow test, Bitumen Extraction test and Density- void ratio analysis

Methods for Testing Asphalt Cement include Particle size distribution, Penetration test, Ring and ball Softening point, Ductility and Air-void in asphalt

2.3 Methods for Testing Asphalt Cement Concrete

Three samples (one per month) of asphalt cement concrete were collected from each of the 5 asphalt plants. The blended mix samples from all the 5 asphalt plants were compacted according to standard procedures[28] and were all subjected to bulk density, Marshall stability, flow and bitumen extraction tests. These tests were conducted to determine the compliance of the blended asphalt cement concrete with the standard specifications. The tests are briefly described as follows:

***Bulk density*:** This was carried out to determine the bulk specific gravity and bulk density of the asphaltic concrete specimens according to ASTM D2726 / D2726M-19 [29].

Marshall Stability and Flow: The stability and flow of the blended asphalt samples were obtained by determining the resistance of the asphalt concrete mixture to the plastic deformation using a compacted cylindrical bitumen specimen which underwent loading up to the maximum load in line with ASTM D6927-15 [30].

Bitumen extraction: This was done to derive the bitumen content in the asphalt cement concrete and expressed as a percentage of the total weight of the asphaltic concrete using centrifuge extractor in accordance with ASTM D8159-19 [31].

2.4 Methods for Testing Asphalt Cement

The extracted asphalt cement samples were further subjected to particle size distribution, penetration, ring and ball softening and ductility tests. Checks were done for the extracted bitumen to determine their compliance to standard specification for quality control and their suitability or adequacy for road construction. The tests conducted on samples of the extracted asphalt cement (bitumen) are discussed as follows:

Penetration: This is an empirical means of determining the consistency or viscosity of asphalt cement using a specified test condition for the purpose of grading the bitumen. It is the depth penetrated by a standard needle into the bitumen sample under specific conditions of load, time and temperature. The penetration test on the asphalt cement samples was conducted in line with ASTM D5/D5M-19 [32].

Ring and ball softening: The temperature when the asphalt cement samples attained a level of softening by which a standard ball passed through the asphalt cement samples falling through 250 mm high mould with the application of heat under glycerin or water at specific test condition was conducted in line with ASTM D36/ D36M-14 [33].

***Particle Size Distribution**:* The grading of aggregates extracted from asphaltic concrete was determined in line with ASTM D5444-15 [34]. The outcome of the gradation showed the agreement of the size distribution of the aggregates with the specified standard requirements and also provided required data for quality control of the aggregates for the production of asphalt cement concrete.

Ductility: This is the measure of the adhesive property of asphalt cement (bitumen) and its capacity to show its elasticity. It is measured in centimeters (cm). Each bitumen sample stretched before breaking as a result of pulling from two ends of a standard briquette specimen of bitumen at a given speed and known temperature. The ductility of the bitumen samples was determined in line with ASTM D113-17 [35].

Air-Void in Asphalt: This is the proportion of void spaces inside the aggregate-binder matrix that are not filled with binder-sufficient voids should be provided to allow for a small amount of additional compaction under traffic and a small amount of asphalt expansion without flushing, bleeding, or loss of stability due to temperature increases. The air-void test was carried out in line with ASTM D3203 / D3203M-17 [36].

3. Results and Discussion

The results obtained from the asphalt cement concrete samples collected from the 5 different plants in the south-western parts of Nigeria at 3 consecutive months is presented in Table 1.

Table 1 - Analysis of asphaltic concrete from different plants

	FMWH Standard	LSPWC	SEQUOIA	CCECC	JBN	ESPRO
Bulk Densities (kg/m^3)	> 2.3	1.98-2.17	2.27-2.31	2.34 -2.35	2.36-2.39	2.33-2.35
Marshall Stability (KN)	> 3.5	6.19-7.56	8.01-10.29	7.85-10.98	12.94-16.53	8.5-10.71
Marshall Flow (mm)	> 3.5	3.5-4.0	3.6-3.8	3.5-4	3.3-3.8	3.6-3.8

Average Bitumen Content (%)	5-8	3.9-5.6	6.4-7.0	6.2-6.3	5.1-6.3	3.9-4.8
Void Ratio (%)	3-5	17.6-20.9	7.4-8.7	5.9-6.7	4.5-5.0	5.4-6.2
Penetration (mm)	60-70	60.7-61.4	63.4-63.7	65.3-66.2	65.8-67	61.4-62.3
Softening point (°C)	47-56	50.3-50.7	50.0-50.2	50.3-50.5	53.5-53.7	51.3-51.7
Ductility Value	> 100	146.5-152.3	152.3-153	155.4-156	162.3-163	151.6-152.2

The bulk density results indicate that the asphalt samples collected from CCECC, ESPRO and JBN met the minimum specification and fell within the specified limits. The samples from the 3 samples above had their bulk density results complied with the FMWH [37] specifications of not less than 2.3 kg/m^3. However, all the samples collected from LSPWC did not comply with the recommended specification for the bulk density. The asphalt samples collected from the SEQUOIA asphalt plant also had bulk densities of 2.27 - 2.31 kg/m^3 indicating inconsistency in conformity to the FMWH [37] recommendation.

The Marshall Stability and Flow of Asphalt Concrete Cement results indicate that all the asphalt samples obtained satisfactorily comply with the FMWH [37] recommendation.

The Bitumen Extraction of Asphalt Concrete Cement results indicate that the asphalt samples collected from CCECC, SEQUOIA and JBN met the minimum specification and fell within the specified limits of not less than 5% while samples collected from LSPWC and ESPRO did not comply with the recommended specification.

The Density-void ratio results indicate that only JBN samples comply with the specification of density void ratio by FMWH [37]. However, the samples obtained from LSPWC were greater compared to CCECC, ESPRO and SEQUOIA despite the fact they failed to comply with the requirement.

The penetration test which indicates the consistency of bitumen results indicate that all of the asphalt plants conform to the FMWH specification. A value of 60/70 grade bitumen shows that its penetration value lies between 60 & 100 used in warm climate to avoid softening because the value of temperature affects the use of the bitumen.
Bitumen is viscous elastic material without sharply defined melting points. They gradually become softer and less viscous as the temperature rises. Therefore, this is a major reason why softening point of bitumen is determined during road construction. The Ring ball and Softening results shows that asphalt samples collected from five (5) asphalt plants comply with the FMWH specification. The higher the softening point value, the tendency of the bitumen to flow at elevated temperature encountered in service.

The Ductility Test indicates a measure of elongation or ability of the bitumen to get stretched before failure. The ductility value obtained on bitumen comply with the FMWH specification in all the samples.

Table 2 - Ductility test on bitumen for 5 asphalt plants

S/N	Sample location	Description	Ductility Value	FMWH Specification	Remark
1	CCECC	1st	155.4	> 100	Okay
		2nd	155.7	> 100	Okay
		3rd	156.0	> 100	Okay
2	ESPRO	1st	151.6	> 100	Okay
		2nd	151.9	> 100	Okay
		3rd	152.2	> 100	Okay
3	JBN	1st	162.3	> 100	Okay
		2nd	162.7	> 100	Okay
		3rd	163.0	> 100	Okay
4	LSPWC	1st	146.5	> 100	Okay
		2nd	146.9	> 100	Okay
		3rd	147.2	> 100	Okay
5	SEQUOIA	1st	152.3	> 100	Okay
		2nd	152.6	> 100	Okay
		3rd	153.0	> 100	Okay

The particle size distribution for the asphalt cement concrete samples collected from the five (5) different plants in the south-western parts of Nigeria at 3 consecutive months are depicted in Figure 1-5. The results indicated conformity of asphalt samples collected from JBN to specified standard while others are inconsistent in meeting the FMWH [37] Volume II specification sample size for wearing course; 1200g.

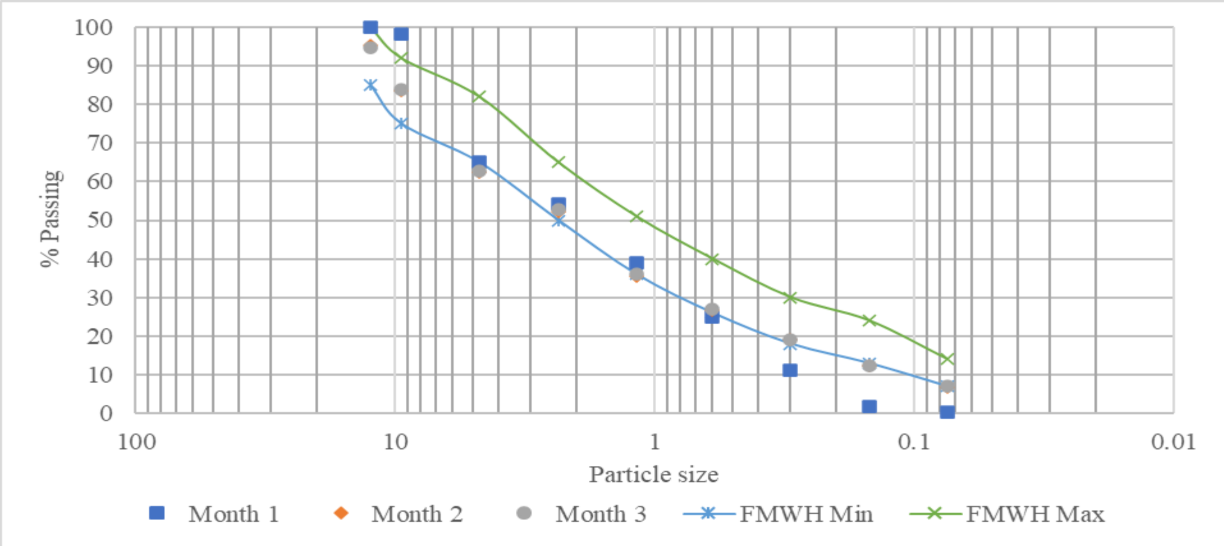

Fig. 1 - The particle size distribution for the asphalt cement concrete from LSPWC

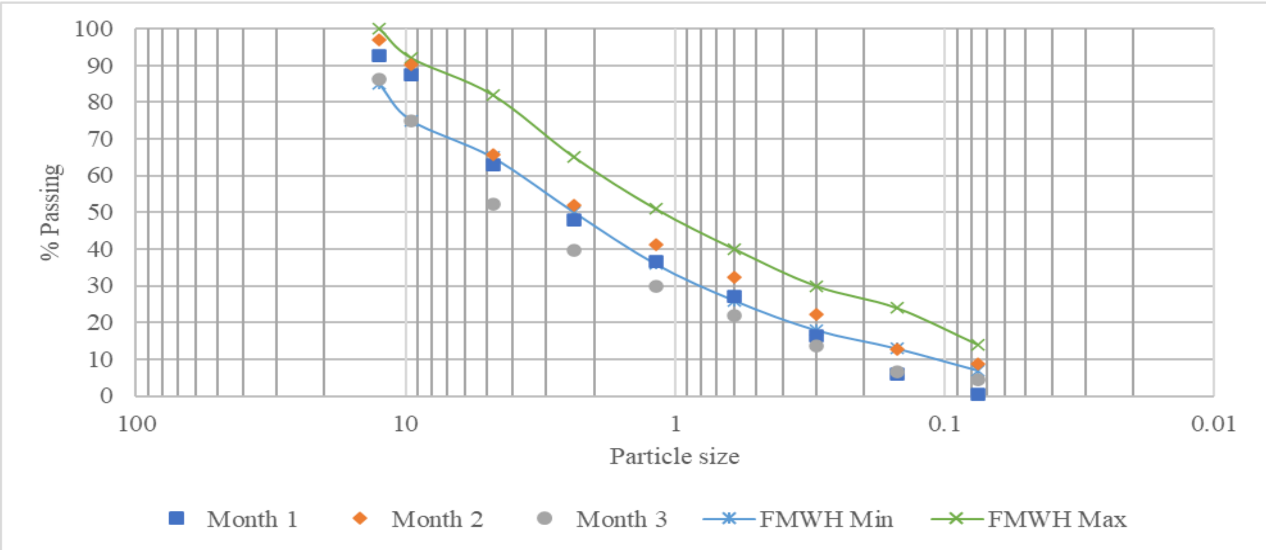

Fig. 2 - The particle size distribution for the asphalt cement concrete from SEQUOIA

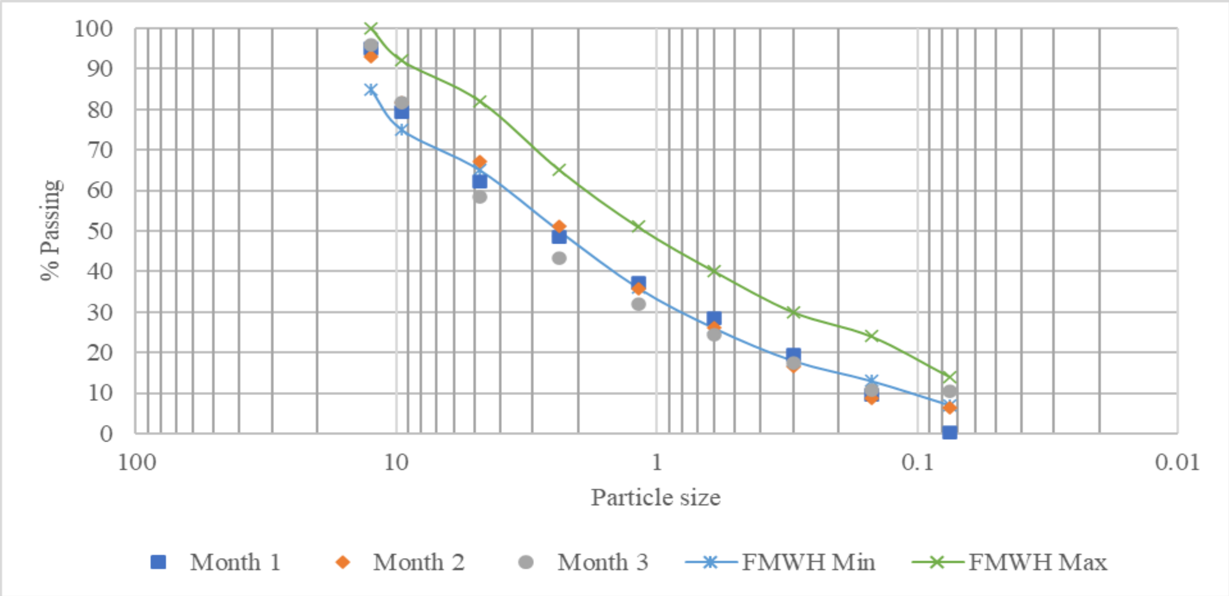

Fig. 3 - The particle size distribution for the asphalt cement concrete from CCECC

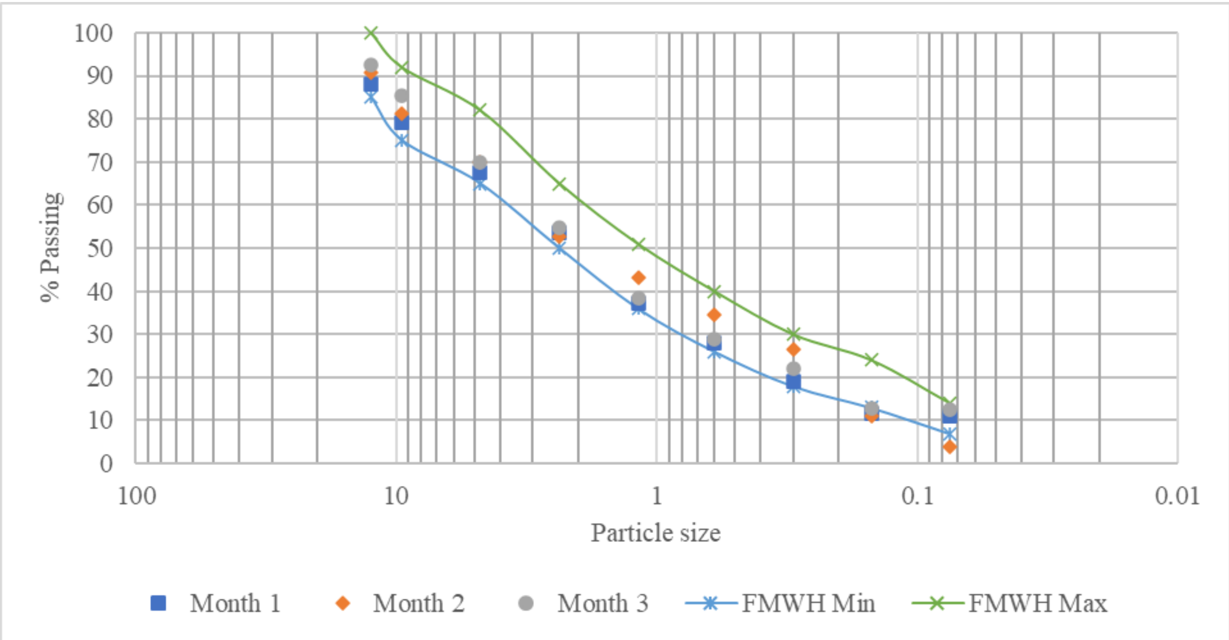

Fig. 4 - The particle size distribution for the asphalt cement concrete from JBN

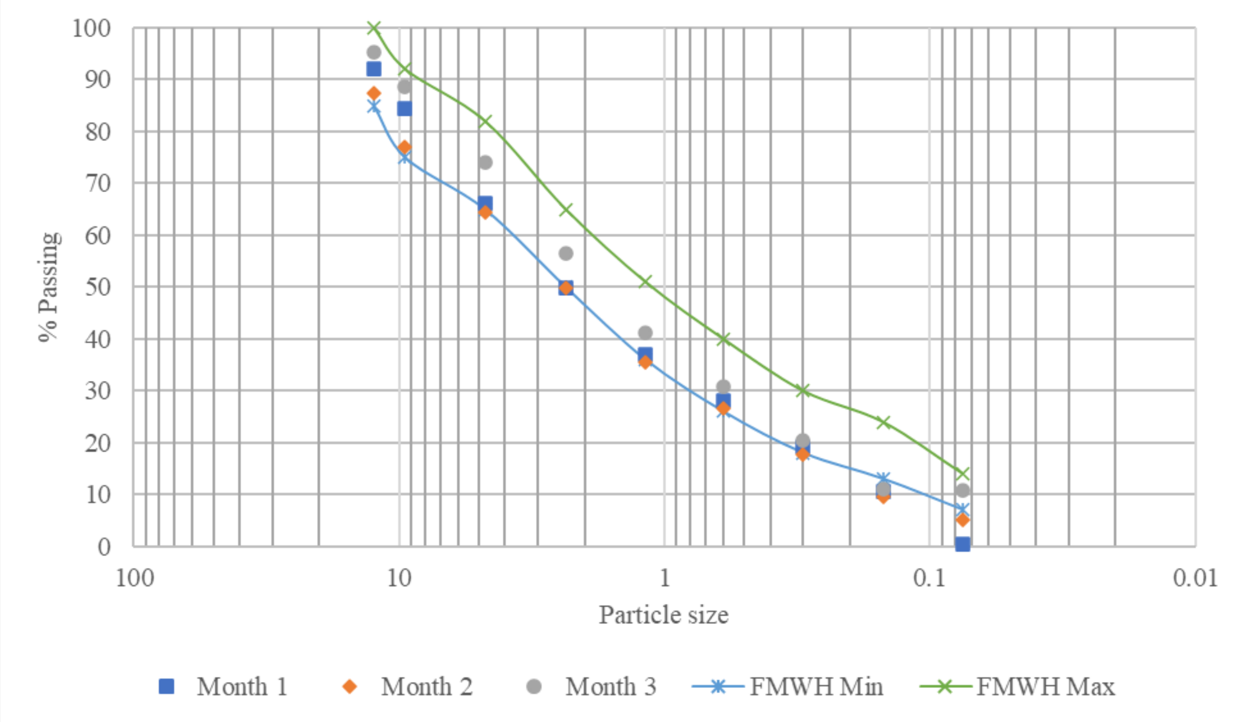

Fig. 5 - The particle size distribution for the asphalt cement concrete from ESPRO

4. Conclusions

Based on the micro-structural and mechanical properties of asphaltic concrete and asphalt cement, the following conclusions were drawn from this project which includes;

In balancing mixing makes the samples fall short of required stability to perform effectively under loading, majorly due to poor mixing ratio of the constituents.

Only JBN samples obtained for the three months (i.e. June, September and October) and blended mix satisfies the standard requirements of FMW's specifications for the quality control such as bitumen grade, air void, bulk density and Marshall Stability &flow but other selected batching plants were not satisfactory enough.

The observed engineering properties of the asphaltic concrete are not consistent in the selected asphalt plants.

The above observations are the evidences that these properties are even more important and it is one of the factors responsible for untimely deterioration of road way in South west of Nigeria. So, over dependence on the materials' certificates from manufacturers should be eradicated.

Finally, it was observed that human errors also contribute to the poor quality of the asphalt concrete mixes being produced.

Asphalt concrete production plants should carry out trial designs before producing from fresh stockpiles of materials.

Proper evaluation of the characteristics of aggregates to be utilized for production of dense graded asphalt concrete should be conducted. The process of crushing appropriate rock materials into different aggregates sizes should be strictly monitored.

Materials to be employed for production of asphalt concrete should be tested in the laboratory before usage. Of special concern is bitumen because a large percentage of bitumen imported into the country is not 60/70 pen grade as recommended.

Regular laboratory tests should be conducted after each batch of asphalt concrete produced in asphalt plants in order to ensure that the mixes produced are in conformity with the standard stipulated in the Federal Ministry of Works Roads and Bridges Specifications. Thus, deficiencies detected could be corrected in the next batch.

Batching plants used in the production of asphalt concrete should be in proper working condition to ensure that the correct amount of constituents' materials is batched and conveyed in the mixing drum at the right temperature and the mix is also turned out at the appropriate time and temperature to prevent the production of overheated asphalt.

Government should make it compulsory for every asphalt plant to build and operate laboratories that are well equipped to test materials purchased for asphalt concrete production.

Acknowledgement

The authors would like to thank the universities for allowing to conduct this research.

References

Sayagh S, Ventura A, Hoang T, et al (2010) Sensitivity of the LCA allocation procedure for BFS recycled into pavement structures. Resour Conserv Recycl 54:348–358. https://doi.org/10.1016/j.resconrec.2009.08.011

Sargin Ş, Saltan M, Morova N, et al (2013) Evaluation of rice husk ash as filler in hot mix asphalt concrete. Constr Build Mater 48:390–397. https://doi.org/10.1016/j.conbuildmat.2013.06.029

ASTM (2016) ASTM D5291-16: Standard Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Petroleum Products and Lubricants. ASTM International, West Conshohocken, PA

Oyedepo OJ (2017) Laboratory Investigation of the Use of Crushed Oyster Shell and Crushed Palm-Kernel Shell in Bituminous Mix Design. Malaysian J Civ Eng 29:15–27

Trivedi JS, Kumar R (2015) Impact of Subgrade and Granular Layer Material Properties on Rutting. Am J Civ Eng Archit 3:64–70. https://doi.org/10.12691/ajcea-3-3-2

Ossa A, García JL, Botero E (2016) Use of recycled construction and demolition waste (CDW) aggregates: A sustainable alternative for the pavement construction industry. J Clean Prod 135:379–386. https://doi.org/10.1016/j.jclepro.2016.06.088

Arun MP, Ganesh PD (2013) " Laboratory E valuation of Usage of Waste Tyre Rubber i n Bituminous Concrete ." Int J Sci Res Publ 3:1–7

Yi-qiu T, Li Z-H, Zhang X-Y, Dong Z-J (2010) Research on High- and Low-Temperature Properties of Asphalt-Mineral Filler Mastic. J Mater Civ Eng 22:811–819. https://doi.org/10.1061/(asce)mt.1943-5533.0000015

Hendriks CF (1994) Certification system for aggregates produced from building waste and demolished buildings. Stud Environ Sci 60:821–834. https://doi.org/10.1016/S0166-1116(08)71513-9

Muench ST, Anderson J, Bevan T (2010) Greenroads: A sustainability rating system for roadways. Int J Pavement Res Technol 3:270–279

Perkins SW (2009) Synthesis of warm mix asphalt paving strategies for use in Montana highway construction. Montana

Mitra A (2012) Fundamentals of Quality Control and Improvement: Third Edition

Minich M (2015) Integrated Paving Process Controlfor a Paving operation. 2

Madu CN (1998) Handbook of Total Quality Management. Handb Total Qual Manag. https://doi.org/10.1007/978- 1-4615-5281-9

Sefidmazgi NR, Tashman L, Bahia H (2012) Internal structure characterization of asphalt mixtures for rutting performance using imaging analysis. Road Mater Pavement Des 13:21–37. https://doi.org/10.1080/14680629.2012.657045

Onsori A (2012) Effects of Aggregate Mineralogy and Crusher Type on the Surface properties of hot mix asphalt. Dokuz Eylül University

Adeboje AO, Kupolati WK, Sadiku ER, et al (2020) Stabilisation of lateritic soil with pulverised ceramic waste for road construction. Int J Environ Eng 10:221. https://doi.org/10.1504/IJEE.2020.107425

Adeboje AO, Kupolati WK, Sadiku ER, Ndambuki JM (2019) Influence of partial substitution of sand with crumb rubber on the microstructural and mechanical properties of concrete in Pretoria, South Africa. Int. J. Environ. Waste Manag. 24:39–60

Bello A, Ige J, Adebanjo A (2015) Flexible Pavement Assessment of Selected Highways in Orolu Local Government South - Western Nigeria. Br J Appl Sci Technol 7:45–61. https://doi.org/10.9734/bjast/2015/15172

Adeboje AO, Olutaiwo AO, Adedimila AS (2013) NSE Technical Transactions 47:1–10

Tarawneh S (2014) Priority of Flexible Pavement Failure Criteria in Jordan in Accordance with Clients ', Consultants ', and Contractors ' Views. Eur J Bus Manag 6:1–14

Ede AN (2014) Cumulative Damage Effects of Truck Overloads on Nigerian Road Pavemen. Int J Civ Environ Eng IJCEE-IJENS 14:21–26

Mahmud K, Gope K, Chowdhury SMR (2012) Possible Causes & Solutions of Traffic Jam and Their Impact on the Economy of Dhaka City. J Manag Sustain 2:. https://doi.org/10.5539/jms.v2n2p112

Kaliba C, Muya M, Mumba K (2009) Cost escalation and schedule delays in road construction projects in Zambia. Int J Proj Manag 27:522–531. https://doi.org/10.1016/j.ijproman.2008.07.003

Adlinge SS, Gupta P a K (2009) Pavement Deterioration and its Causes. Mech Civ Eng 9–15

Andriejauskas T, Vorobjovas V, Mielonas V (2014) Evaluation of skid resistance characteristics and measurement methods. In: 9th International Conference on Environmental Engineering, ICEE. VGTU Press, Vilnius, Lithuania

Garber NJ, Hoel L a (2009) Traffic and Highway Engineering, Fourth. Cengage Learning, Toronto

Zaumanis M, Mallick RB, Poulikakos L, Frank R (2014) Influence of six rejuvenators on the performance properties of Reclaimed Asphalt Pavement (RAP) binder and 100% recycled asphalt mixtures. Comput Chem Eng 71:538–550. https://doi.org/10.1016/j.conbuildmat.2014.08.073

ASTM (2019) ASTM D2726/D2726M-19 Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Asphalt Mixtures. ASTM International, West Conshohocken, PA

ASTM (2015) Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures,. ASTM International, West Conshohocken, PA.

ASTM (2019) ASTM D8159: Standard Test Method for Automated Extraction of Asphalt Binder from Asphalt Mixtures. ASTM International

ASTM (2019) ASTM D5/D5M-19a: Standard Test Method for Penetration of Bituminous Materials. ASTM International, West Conshohocken, PA

ASTM (2014) ASTM D36/D36M-14: Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus). ASTM International, West Conshohocken, PA

ASTM (2015) ASTM D5444-15: Standard Test Method for Mechanical Size Analysis of Extracted Aggregate. ASTM International, West Conshohocken, PA

ASTM (2017) ASTM D113-17 Standard Test Method for Ductility of Asphalt Materials. ASTM International

ASTM (2017) ASTM D3203/D3203M-17: Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures. West Conshohocken, PA

FMWH (1997) GENERAL SPECIFICATIONS(ROADS AND BRIDGES). Federal Highway Department: FEDERAL MINISTRY OF WORKS & HOUSING , Government of the Federal Republic of Nigeria, Abuja