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Evaluations of distresses in pavement layers for selected locations in southeastern Nigeria

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ABSTRACT

This paper reports on the distresses of pavement layers for selected locations in southeastern Nigeria. Samples of resident soils at depths of 0.5m, 0.75m and 1m were collected alongside with the asphalt concrete from the areas exhibiting serious distresses on selected roads in Anambra, Enugu and Imo states, all in southeastern Nigeria. The gradation and Atterberg limits tests show that the resident soils have majority of their particles passing through the No 200 BS sieve in the range of 34.5% and 93.6%. They have higher plastic limit values in the range 47% to 96%. According to AASHTO classification, they belong to the soil group A-7-5, showing that they are mainly constituted of clayey soils and have fair to poor subgrade rating. British Standard Light (BSL) and West African Standard (WAS) compaction energies were used for the sub-base and subgrade soils compaction respectively. The maximum dry density (MDD) ranged between 1.76gm/cc and 2.165gm/cc while optimum moisture content (OMC) ranged between 8% and 15%. Three-point CBR at OMC for the sub-base soils range from 6% to 17% while those for the subgrade soils range between 1% and 3%. A plot of the grading of the asphalt materials for the three samples fell within the specified grading envelope. Also, the Marshall Stability and flow of the materials were within the acceptable limits.

Keywords: Distresses, Pavement, Resident soils, Asphalt concrete, Marshall Stability, South-eastern Nigeria

1. INTRODUCTION

In Nigeria, as well as other developing countries of the world, road pavements predominantly provide the basic means of transporting goods and services. Thus, there is need for effective design and planning of these pavements since properly constructed road networks enhance the economic growth of any nation [10] Distresses in road pavements adversely affect the smooth movement of goods and services from one part of the country to the other. Most of the road accidents recorded in Nigeria today are traceable to the poor conditions of the country's road pavements. As a result, a lot of lives have been lost, goods damaged, vehicles bashed, adjoining facilities to the roads grounded and several man hours lost. Despite the huge financial resources being mapped out in the country's annual budget for the transportation sector, most of these paved roads are always in deplorable states. Most of the newly built and rehabilitated roads of the country do not last long enough before failure [3]. Southeastern Nigeria comprises of five states namely: Abia, Anambra, Ebony, Enugu, and Imo. Just like other roads in the country, most of the roads in this zone are facing this problem of incessant pavement distresses/failures. The roads in this part of the country are predominantly of the asphaltic-flexible pavement type. Asphaltic pavement is an example of a multi-layered system which comprises of the surfacing, base course, sub-base, and subgrade [20, 23, 24, 26]. It serves the basic function of receiving loads from the traffic stream and transmitting them through its various layers down to the subgrade. Thus, the durability and the strength of the pavements depend so much on the properties and conditions of these component layers. The surface of the pavement is usually prepared to provide suitable riding surface, sufficient skid resistance, favourable reflection of light and proper drainage [5].

Over the years, the issue of distresses in road pavements has been of much concern to highway engineers. Consequently, several studies have been carried out by researchers in a bid to develop better means of detecting and correcting these distresses. [19, 25], in their study of the initial classification algorithm for pavement distress images using features fusion, proposed an algorithm which achieved an effective classification of pavement distress images with high accuracy. Also, in other to describe the functional and structural conditions of a pavement structure, [9] successfully developed an International Roughness Index (IRI) from visible pavement distresses in AL-Diwaniyah city roadways, Iraq. They developed this model between the IRI and different forms of pavement distresses and examined the effects of these distresses on pavement roughness. [16]; reviewed various pavement distress detection methods and, therein, evaluated the efficiency of the data collection and extraction to the type of distresses, considering the distress detection, classification, and quantification phases of the procedure. Some other researchers that have studied various methods of detecting and dealing with asphalt pavement distresses include: [8]; [9]; [17]; [18]; [21].

Many factors are responsible for failures in highway pavements. As the pavements age and experience repetitions of traffic, they accumulate distresses. The performance and serviceability of the pavements are affected when distressed by any of the following factors: excessive traffic loads, weather (e.g. temperature), water (drainage deficiency), design and construction errors, as well as poor or lack of maintenance [12].

2. METHODOLOGY

The soils and asphaltic concrete samples were collected from three major roads in three of the states in southeastern Nigeria, namely: Awkuzu in Anambra state, along Onitsha-Awka-Enugu Highway (latitude 6.24041243621663^{0}N and longitude 6.952883563935757^{0}E), Ugwuoba in Enugu state, along Enugu-Onitsha Expressway (latitude 6.24765743243533^{0}N and longitude 6.971677802503109^{0}E) and Arondizuogu in Imo state, along Awka-Okigwe road (latitude 5.888536183409156^{0}N and longitude 7.166458815336227^{0}E).

Fig.1: Soil samples collection from test pits

Geology of the Study Areas

A brief description of the geology of the study areas (Anambra, Enugu, and Imo states) will be presented in this section. As already stated, the roads in these areas are predominantly of the flexible pavement type. [13]; classified these roads as trunk A, trunk B and

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Trunk C. Although the classification of these roads is outside the scope of this work, it is worthwhile to mention the fact that trunk A roads are roads managed by the federal government, while Trunk B roads are managed by the state governments and trunk C roads managed by local governments.

Fig. 2: Distressed portions of the road pavements

Materials

The materials used in this study are the asphaltic concrete (AC) and soil samples (SS) collected from the different sampling locations.

Samples collected from Anambra state are denoted as Sample A. Thus, the asphaltic concrete sample from this state is denoted as AC_A. The soil samples will be denoted as SS_A, with soil samples collected at 0.5m depth labelled as SS_{A1}, the ones from 0.75m depth as SS_{A2}, and the ones collected at 1m depth labelled as SS_{A3}.

Samples collected from Enugu state are denoted as Sample B. The asphaltic concrete sample from this state is labelled as AC_B. The soil samples from here will be denoted as SS_B, with soil samples collected at 0.5m depth labelled as SS_{B1}, the ones from 0.75m depth as SS_{B2}, and the ones from 1m depth as SS_{B3}.

Samples collected from Imo state are denoted as Sample C. Thus, the asphaltic concrete sample from this state is denoted as AC_C. The soil samples from here are labelled as SS_C, with the soil samples collected at 0.5m depth as SS_{C1}, the ones collected at 0.75m depth as SS_{C2}, and the ones from 1m depth as SS_{C3}.

Methods

The adopted methods of testing for the soil samples are in line with the BS:1377- methods of testing for soils for geotechnical engineering purposes. The tests to be carried out on the soil samples and asphaltic concrete were: Gradation test (sieve analysis), Atterberg limit tests (liquid limit, plastic limit and shrinkage limit), compaction test, California bearing ration test (CBR), bitumen extraction test, Marshall Stability and flow.

Gradation Test (Sieve Analysis)

The main aim of this gradation test, equally known as particle size distribution analysis, is to grade and classify soils. It is mostly used for coarse-grained soils. The relative proportion of the different particle sizes contained in a soil is derived from this analysis. The predominance of any of gravel, sand, silt or clay in a soil is also determined as well as the determination of which of the ranges controls the engineering behaviour of the soil sample.

Atterberg Limit Tests

This test consists in the determination of the liquid limit, plastic limit and plasticity index. Atterberg limits are basic measures of the critical water contents of a fine-grained soil. It is based on the principle that depending on the water content, a soil may appear in one of four states: solid, semi-solid, plastic and liquid.

Compaction Test

The compaction test is a laboratory method of experimentally determining the optimal moisture content (OMC) at which a given soil type will become most dense and achieve its maximum dry density (MDD). The test generally consists of compacting soils at known moisture content into a cylindrical mould with a collar of standard dimensions of height and diameter using a compactive effort-controlled magnitude.

California Bearing Ratio (CBR)

The California Bearing Ratio test is a penetration test used to evaluate the subgrade strength of roads and pavements. The results of these tests are used with the curves for determination of the thickness of pavement and its component layers. Thus, the strength of the subgrade, sub-base and base courses are usually expressed in terms of their CBR values. This test can be carried out in the soaked or unsoaked conditions. The soaked condition models the behaviour of the pavement when submerged/soaked by water.

Bitumen Extraction Test

This test is used to determine the percentage of bitumen content present in the asphaltic concrete pavement by the cold solvent extraction method. Usually, the properties of flexible pavements such as their durability, compatibility, and resistance from defects like bleeding, ravelling, and ageing are mainly dependent on the percentage of bitumen used with the aggregates in laying the pavement.

This test is usually carried out with the use of apparatuses such as a centrifuge, a balance of capacity 500 grams with sensitivity of 0.01 grams, a thermostatically controlled oven with capacity up to 2500^{o}C, and a beaker for collecting the extracted bitumen. Benzene usually serves as the solvent which is used to submerge the asphalt sample for the bitumen extraction.

Marshall Stability and Flow

Bituminous mixes are used in the surface course of road and airfield pavements. The desirable bituminous mix properties include stability, density, durability, flexibility, resistance to skidding and workability during construction.

3. RESULTS AND DISCUSSION

The grain size distribution of the resident soils, as summarized in Table 1, shows that the percentage retained in No. 200 BS sieve ranges between 0.6% and 6.2%, while the cumulative percentage passing No. 200 BS sieve are within the range of 34.5% and 93.6%. This implies that there is a higher percentage of fines than sand in the different layers of soils collected from the three states.

In accordance with AASHTO soil classification, soils with more than 35% passing No. 200 BS sieve are classified as silty-clay materials. The soils in this study fall within this category, apart from SS_{B1} which slightly fell out with 34.5% passing. The liquid limits (LL) for the soil samples range from 47% to 96.4%, while their plasticity indices range from 20% to 47%. Thus, they can be said to belong o the soil group A-7-5, showing that they are mainly constituted of clayey soils and have their subgrade rating as fair to poor. In line with the Federal Ministry of Works and Housing (1997) specification, only soils with less than 35% passing No. 200 BS sieve can be used for base and sub-base materials [6]. It is, therefore, evident that all the samples are not suitable for base and sub-base construction, unless they are properly stabilized.

Table 1: Physical Properties of the Resident Soils

Properties	**Anambra**			**Enugu**			**Imo**		
	SS_{A1}	**SS_{A2}**	**SS_{A3}**	**SS_{B1}**	**SS_{B2}**	**SS_{B3}**	**SS_{C1}**	**SS_{C2}**	**SS_{C3}**
Grain size Distribution									
% retained in No. 200 sieve	0.8	0.6	3.3	2.8	6.2	3.4	0.7	0.9	2.5
% passing through No. 200 sieve	93.6	90.2	68.9	34.5	36.3	38.9	92.7	89.4	76.7
Atterberg Limits									
Liquid Limit (%)	95	92	78	47	48	49	96.4	90.9	78.4
Plastic Limit (%)	48	48	41	27	25	25	58.2	46.5	41.1
Plasticity Index (%)	47	44	37	20	23	24	38.2	44.4	37.3

Source: Laboratory Analysis

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According to Unified Soil Classification System (USCS), the soils from Anambra and Imo may be referred to as organic silts and clays of high plasticity (OH), since they have their liquid limits greater than 50%. The soils from Enugu state have their liquid limits slightly less than 50% (47, 48, and 49%) and thus could be said to be organic silts and clays of low plasticity (OL).

Table 2: Compaction Characteristics of the Soils

SA1	sub-base	Moisture content	10.2	12.5	14.3	16	18.2
		Dry density	1.59	1.68	1.7	1.6	1.5
	subgrade	Moisture content	10.2	12.2	14.1	16	18.1
		Dry density	1.47	1.56	1.62	1.19	1.09
SA2	sub-base	Moisture content	10.3	11.9	14.3	16.1	18.1
		Dry density	1.65	1.68	1.72	1.65	1.54
	subgrade	Moisture content	10.2	12.2	13.9	16.1	18.3
		Dry density	1.55	1.58	1.6	1.54	1.46
SA3	sub-base	Moisture content	10	11.9	14.3	16.1	18
		Dry density	1.65	1.66	1.7	1.6	1.51
	subgrade	Moisture content	10	12.1	14.3	16.2	18.3
		Dry density	1.58	1.62	1.65	1.56	1.49
SB1	sub-base	Moisture content	8.3	10.4	13.3	14.5	16.3
		Dry density	1.78	1.81	1.85	1.8	1.68
	subgrade	Moisture content	8.2	10.3	12.3	14.2	16.2
		Dry density	1.59	1.61	1.63	1.58	1.43
SB2	sub-base	Moisture content	8.4	10.3	12.7	14.7	16.5
		Dry density	1.79	1.83	1.86	1.77	1.69
	subgrade	Moisture content	8	10.3	12.2	14.1	16.3
		Dry density	1.59	1.59	1.63	1.57	1.48
SB3	sub-base	Moisture content	8.3	10.5	12.4	14.8	16.4
		Dry density	1.78	1.81	1.85	1.75	1.6
	subgrade	Moisture content	8.2	10.2	12.1	14.1	16
		Dry density	1.69	1.66	1.69	1.61	1.51
SC1	sub-base	Moisture content	10.4	10.8	11.4	12.1	18.5
		Dry density	1.53	1.68	1.74	1.7	1.48
	subgrade	Moisture content	10.5	11.2	11.9	13.1	16.2
		Dry density	1.51	1.58	1.68	1.57	1.51
SC2	sub-base	Moisture content	10.3	11.2	12.8	14.6	15.2
		Dry density	1.67	1.72	1.78	1.69	1.6
	subgrade	Moisture content	10	10.8	12.25	14.1	14.8
		Dry density	1.55	1.62	1.73	1.58	1.52
SC3	sub-base	Moisture content	8.3	10.1	12.4	13.8	17.8
		Dry density	1.67	1.68	1.71	1.68	1.52
	subgrade	Moisture content	8.3	10	12.1	14.2	16.1
		Dry density	1.61	1.65	1.68	1.59	1.52

Source: Laboratory Analysis

It can be observed from Table 2 that the dry densities of the materials, when compacted for sub-base are higher than those for subgrade. This result is based on West African Standard (WAS) compaction was employed on the soils for sub-base conditions while British Standard Light (BSL) compaction was used for the subgrade. The WAS has a higher compaction energy than the BSL,

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which is the reason why it produced higher values of maximum dry densities (MDD) for the sub-bases than the BSL for the subgrades. The optimum moisture contents (OMC) are relatively close for both the sub-base and subgrade soils under the two compactive efforts (BSL and WAS). [14]; outlined the ranges of values that may be predicted when using the standard proctor test methods as follows: for clay, maximum dry density (MDD) may fall between 1.44gm/cc and 1.685gm/cc and optimum moisture content (OMC) may fall between 20-30%. For silty-clay MDD is usually between 1.6gm/cc and 1.845gm/cc and OMC ranged between 15% - 25%. For clayey or silty-sand, MDD usually ranged between 1.76gm/cc and 2.165gm/cc and OMC between 8% and 15%. Therefore, checking at the results of these soil, it could be noticed that they are clayey or silty sand materials.

California Bearing Ratio (CBR) Characteristics of the Soil

Three-point CBR values have been plotted against moisture contents in Figures 3 to 5. The three-point CBR provides a clear understanding of the ground conditions under different conditions. The samples are usually prepared in three different moulds of different densities and moisture contents. This allows the soils' CBR performance to be understood at different levels of compaction as opposed to the one-point test that is very specific to a particular density and moisture content.

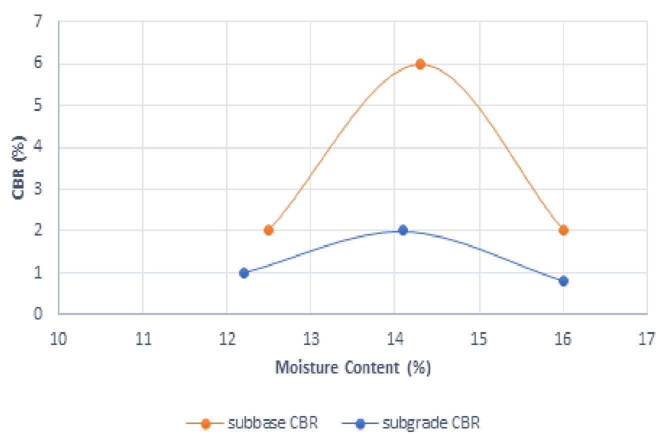

Fig. 3(a): CBR versus Moisture Content for Sample SS_{A1}

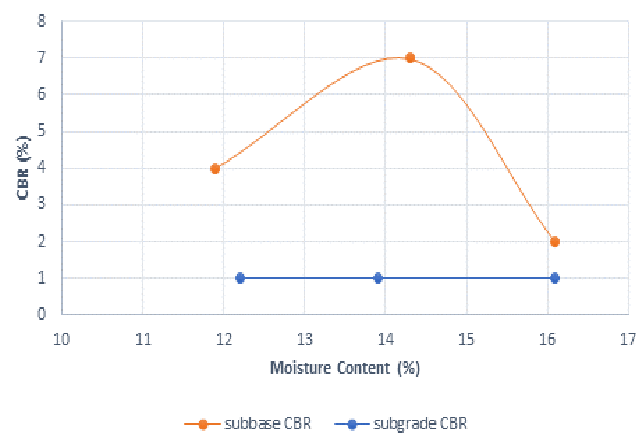

Fig. 3(b): CBR versus Moisture Content for Sample SS_{A2}

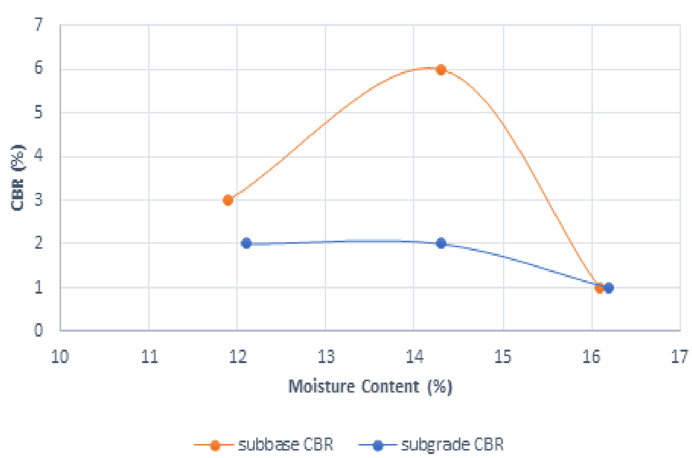

Fig. 3(c): CBR versus Moisture Content for Sample SS_{A3}

From Figures 3(a) to 3(c), it can be observed that the CBR values at OMC for the sub-base soils range from 6% to 7%, while those for the subgrade soils range between 1% and 2%. The minimum CBR value of a sub-base soil should be 20% and 30% for traffic up to 2 msa and traffic exceeding 2 msa respectively. Also, the minimum CBR value for a subgrade soil is usually 6%, although subgrade characterization recommends 10% [4]. Therefore, the CBR values are not good enough for sub-base and subgrade layers, perhaps as a result of the high percentage of fines as highlighted in the particle size distribution (Table 1).

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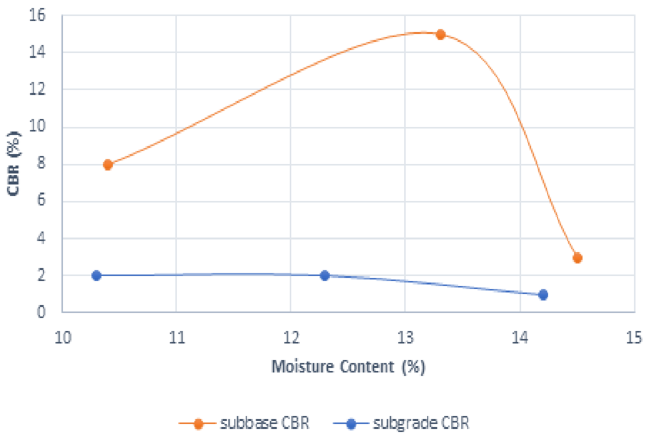

Fig. 4(a): CBR versus Moisture Content for Sample SS_{B1}

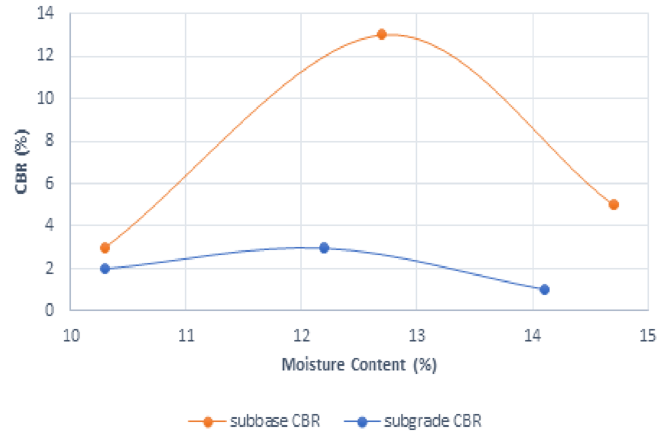

Fig.4 (b): CBR versus Moisture Content for Sample SS_{B2}

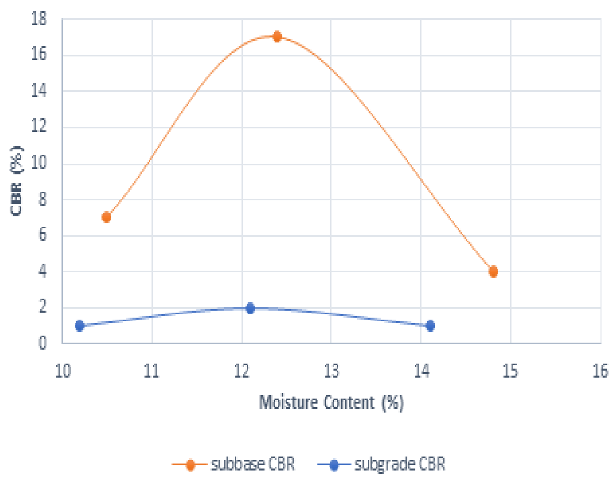

Fig. 4(c): CBR versus Moisture Content for Sample SS_{B3}

Fig. 4(a – c) show that the CBR values at OMC for Enugu's sub-base soils range from 13% to 17%, while that for sugrade range from 2% to 3%. These values are below the minimum values of 20% and 6% for sub-base and sugrade soils respectively. Thus, the reident soils do not possess the required CBR values for sub-base and subgrade and are not good for pavement construction.

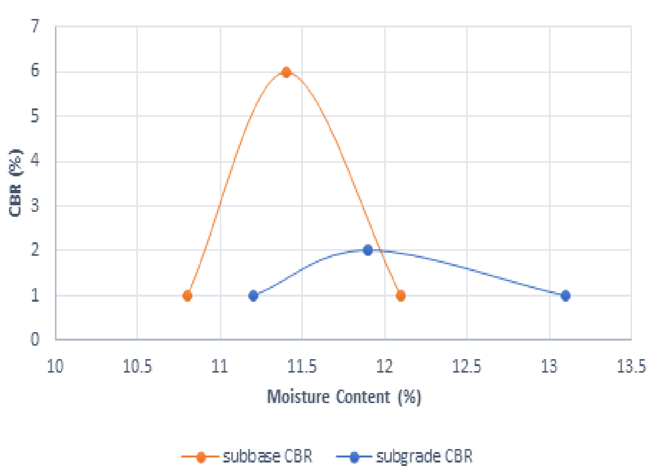

Fig. 5(a): CBR versus Moisture Content for Sample SS_{C1}

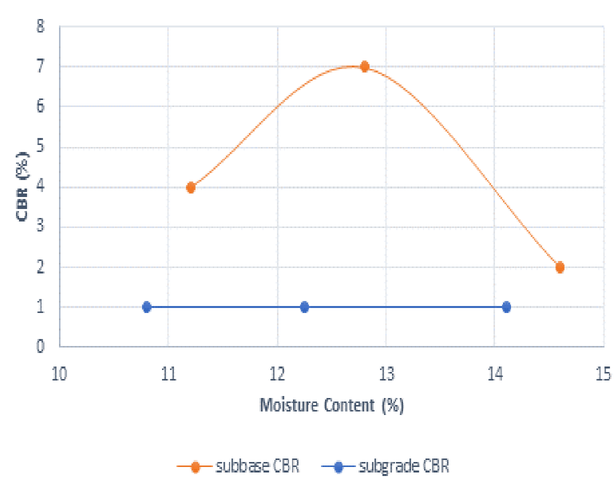

Fig. 5(b): CBR versus Moisture Content for Sample SS_{C2}

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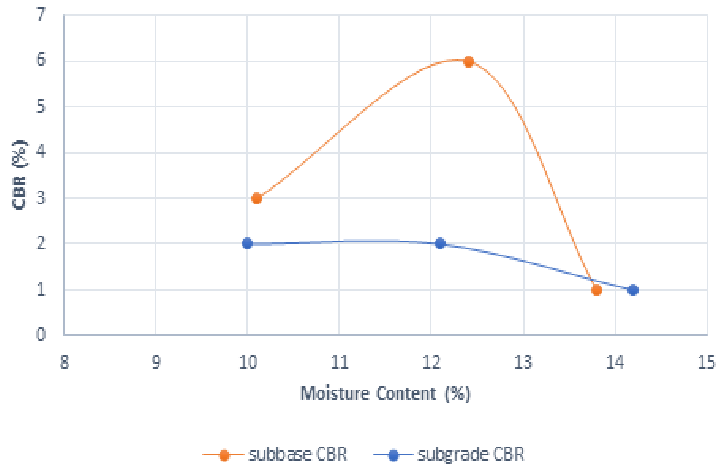

Fig. 5(c): CBR versus Moisture Content for Sample SS_{C3}

The CBR values at OMC for sample SS_C (Imo state) are shown in Figures 5(a – c). For the sub-base, the values ranged from 6% to 7%, similar to Sample SS_A, while it ranged from 1% to 2% for the subgrade. These values are also below the minimum CBR values for sub-base and subgrade soils. As a result, the soils are not suitable for pavement construction. This is in line with the findings of [22]; [15]; [1]; [11]; [2]; in their various studies.

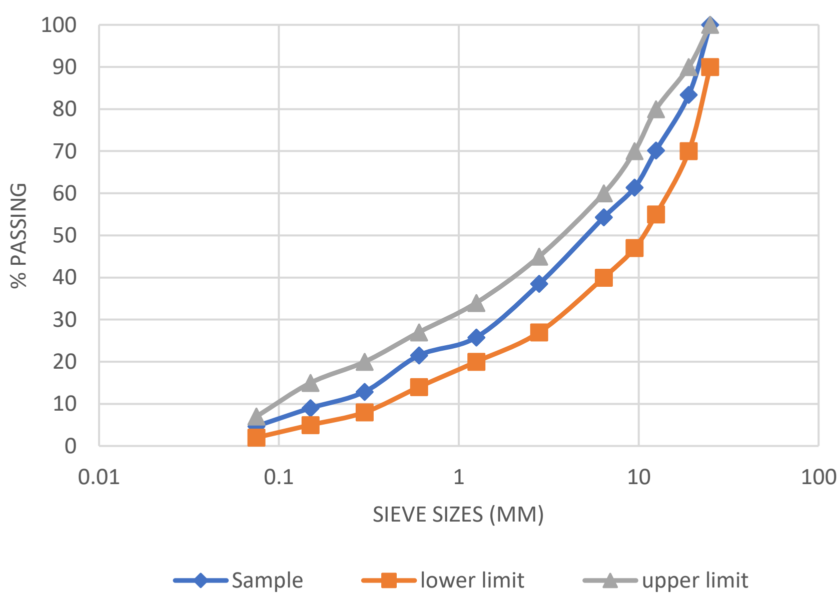

Fig.6 (a): Grading Envelope for Binder Course of Sample AC_A

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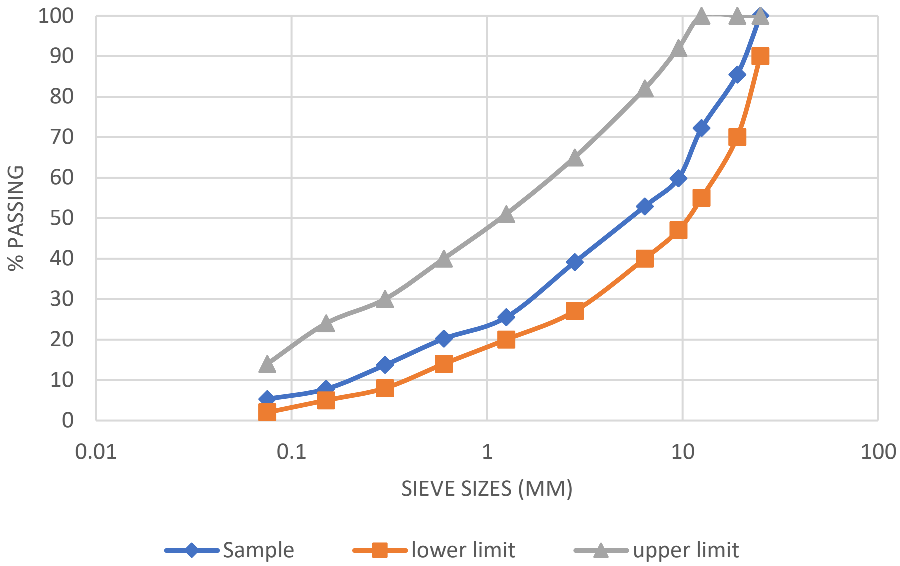

Fig. 6(b): Grading Envelope for Wearing Course of Sample AC_A

The grading envelopes for the wearing and binder courses of the asphalt concrete for sample AC_A have been plotted in Figures 6(a) and 6(b). For the efficient performance of flexible pavements, the asphalt concrete mixes in the binder and wearing courses of the pavements must fall within the specified upper and lower limits of percentage passing by weight which forms the grading envelope. It can be observed that the asphalt sample from Anambra state has their aggregate gradings falling within the grading envelopes.

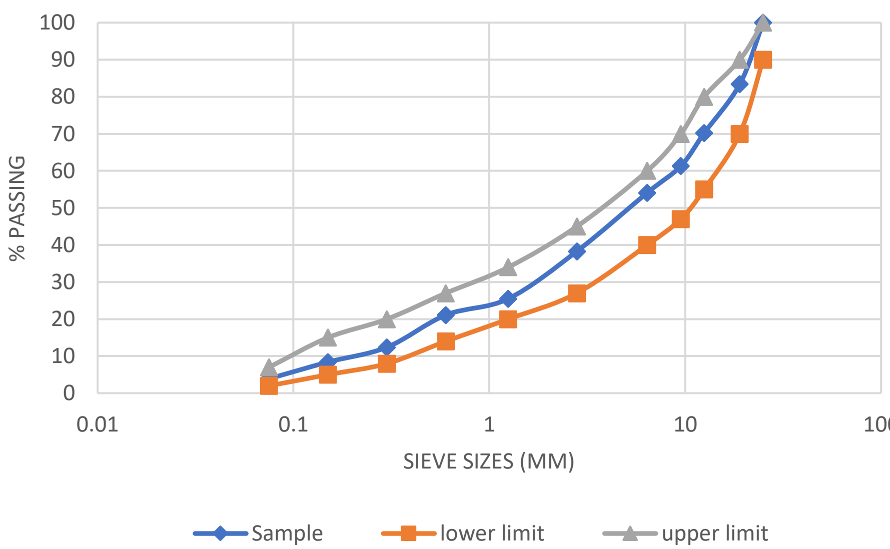

Fig.7 (a): Grading Envelope for Binder Course of Sample AC_B

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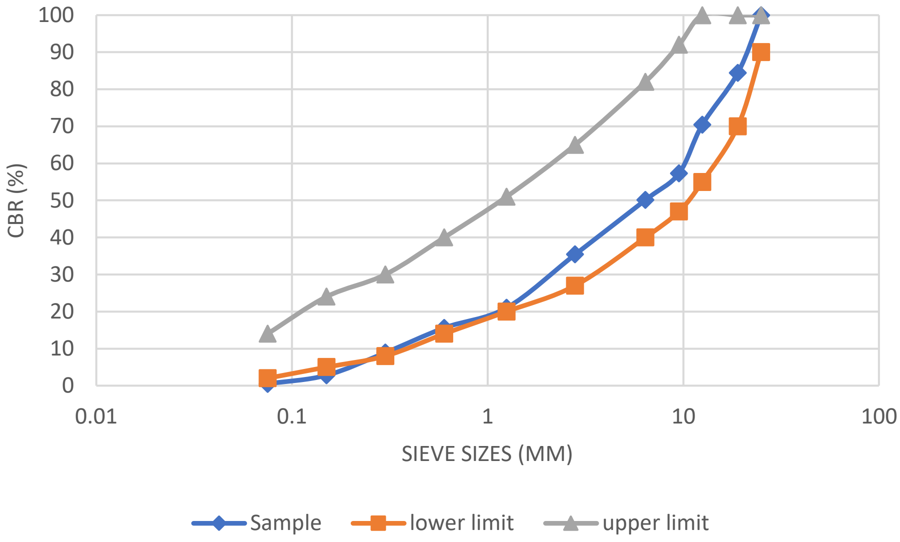

Fig. 7(b): Grading Envelope for Wearing Course of Sample AC$_B$

Figures 7(a) and 7(b) show the plots of the grading envelopes for the binder and wearing courses of sample AC$_B$. It can be observed that the asphalt concrete mixes for the both courses fell within the specified upper and lower limits of the percentage passing weight. Thus, the asphalt concrete at this location can be said to be of sufficient and suitable particle compositions.

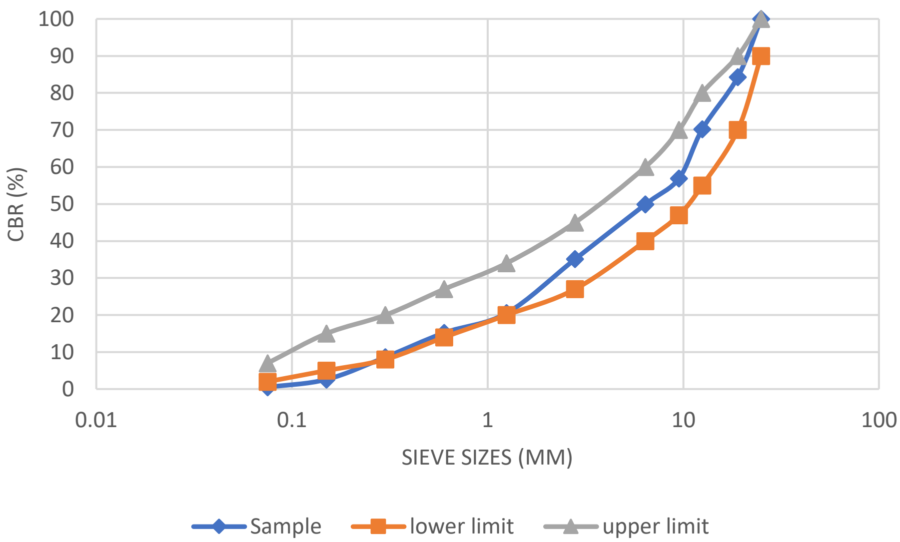

Fig.8 (a): Grading Envelope for Binder Course of Sample AC$_C$

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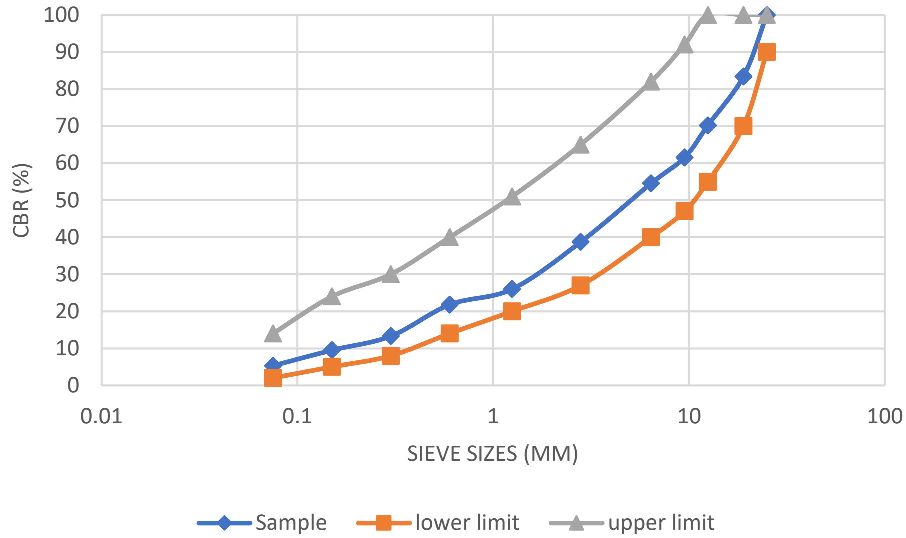

Fig.8 (b): Grading Envelope for Wearing Course of Sample AC_C

The plots in Figures 8(a) and 8(b) demonstrates the particles grading of sample AC_C when compared to the specified upper and lower limits of percentage passing by weight. It can be observed that sample's grading curve for the binder and wearing courses fell within the specified grading limits. This implies that the asphalt concrete at the location has proper aggregate composition.

Marshall Stability and Flow

The results of Marshall Stability and flows for the asphalt concrete samples are as tabulated in Table 3. The values of stability in kN required for the efficient performance of a flexible pavement should be greater than or equal to 3. Also, the flow values for the binding course should be within the range of 2 and 4 mm, while that for wearing course should be between 2 and 6 mm. The stability of the asphalt samples from the three states are way above the 3mm minimum value, while the flows fell within the ranges of 2 - 4 mm and 2 - 6 mm for both the binder and wearing courses respectively.

Table 3: Marshall Stability and Flow Characteristics

Properties	Binding Course			Wearing Course		
	AC_A	AC_B	AC_C	AC_A	AC_B	AC_C
Bit. Cont. by wt. of aggregate. (%)	5.1	5.2	5.0	5.2	5.2	5.1
Bulk density (gm/cm^3)	2.24	2.28	2.16	2.05	2.12	2.01
S.G. aggregate.	2.71	2.74	2.69	2.68	2.70	2.67
Correction Stability (kN)	10.6	11.1	10.4	10.4	10.9	9.8
Flow (mm)	2.2	2.3	2.1	2.9	3.1	2.6

Source: Laboratory Analysis

For binder courses, it is specified that the bitumen content percentage by weight of aggregate ranges from 4.5% to 6.5%, while that for wearing courses range from 5% to 8.0%. The bitumen contents in the binder and wearing courses of the asphalt samples fell within the specified limits.

4. CONCLUSION

The physical characteristics, compaction and strength characteristics of the resident soil samples collected from the areas of serious distresses as well as the properties of the corresponding asphalt concrete materials from the selected roads in the three of Nigeria's southeastern states of Anambra, Enugu, and Imo has been carried out in this study. The results of the gradation and Atterberg limits tests show that these resident soils have majority of their particles passing the No 200 BS sieve in the range of 34.5% and 93.6%. This implies that these soils have higher percentages of fines than sand. These soils have higher plastic limit values (in the range 47% to 96%). Therefore, according to AASHTO classification, they belong to the soil group A-7-5, showing that they are mainly constituted of clayey soils and have fair to poor subgrade rating. The British Standard Light (BSL) and West African Standard (WAS) compaction energies were used for the sub-base and subgrade soils compaction respectively. The maximum dry density (MDD) ranged between 1.76gm/cc and 2.165gm/cc and optimum moisture content (OMC) between 8% and 15%. This shows that the soils are of clayey or silty sand materials. Three-point CBR was carried out on the samples to ensure proper evaluation of the materials under various conditions. The CBR values at OMC for the sub-base soils range from 6% to 17%, while those for the subgrade soils range between 1% and 3%. These values are low, probably as a result of high fines contents, thereby making the soils unsuitable for sub-base and subgrade applications. The binder and wearing course materials for the three asphalt samples (AC_A, AC_B, AC_C) were plotted in the grading envelope. The samples have their aggregate gradings falling within the grading envelopes. Also, the bitumen contents in the binder and wearing courses of the asphalt samples fell within the specified limits. Thus, all the asphalt samples are of suitable compositions. The results of Marshall stability and flow tests showed that the samples' values fell within the specified limits. This implies that the asphalt concrete, on its own, is properly laid and could have stood the test of time.

Future Scope

Various research outputs on the causes of road pavement distresses in southeastern Nigeria has been recorded in various publications (local and international). The reports mainly point on poor design and construction methods, inadequate supervision, and poor maintenance cultures among others as the causes of these undue distresses in the pavements. Although these factors contribute to these distresses, a more detailed investigation on the material constituents of the pavements is needed. This will help in identifying the deficiencies in the material properties as well as observing the adequacy of the various mix proportions applied in the failed portions of the pavements. Deeper investigations into the chemical properties of the pavement materials (soils and asphalt) in the region can be carried out in order ascertain various other remote causes of these failures.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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