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A review of the mineralogical and geotechnical properties of some residual soils in relation to the problems of road failures: A case study of Nigeria

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Abstract. Poor geotechnical and mineralogical properties of soils used for road construction are a significant factor responsible for pavement failures. This is because most soils encountered at failed portions of some pavements do not meet the specifications according to relevant standards. It is with this in mind that this study carried out a systemic review on some residual soils in Nigeria, with a focus on their locations, geotechnical, and mineralogical properties in comparison to standards specified in the Nigerian specification for road and bridges. This study also reviewed how these properties have contributed to various road failures in different regions of the country. It was observed that the geotechnical and mineralogical properties of most residual soils in some regions of Nigeria did not meet up with the standards stipulated by the Nigerian Specification for road materials. Reviews carried out on the place of geotechnical and mineralogical characteristics on various road failures in Nigeria showed that a high volume of research works was carried out in the south-western and southeastern parts of the country compared to the Northern region.

Keywords: Geotechnical, mineralogical, specification, failures, road, review

1. Introduction

Poor geotechnical and mineralogical properties of residual soils used in the construction of roads globally may result in road pavement deterioration [1]. Most countries have stipulated standards for the geotechnical properties of soils when used for road construction. The Nigerian Specification for Road and Bridges [2] specified standard ranges for the geotechnical and mineralogical properties of soils before they can be used for road construction. Such as; for a soil to be used as a base course or sub-base material, percentage of soil particles passing sieve No. 200 should not be greater than 35 % [3]. But not all soils meet these stipulated standards because they have varied behaviours depending on their geotechnical and mineralogical properties [4]. Soils formed in situ by chemical and mechanical weathering of parent rocks are termed residual soils [5], and they have chemical similarity to their parent formation material [6]. In Nigeria, some soils used for road construction were observed to have originated from parent formation materials with poor



geotechnical properties. This is the reason why, Kekere, Lawal, and Awotayo [7] in their research work stated that Nigerian roads are an infrastructural facility on the verge of total collapse. Despite enormous expenditures continuously being spent by the government on reconstruction and maintenance, travelling on Nigerian roads are said to be a nightmare due to the terrible conditions of the pavement, [8]. Figure 1 (a – c) gives illustrations to the extent most roads deteriorate in Nigeria. These failures range from partial to full pavement failure.



Figure 1. (a) Kaduna – Abuja road (North Central Nigeria), (b) Otukpa-Otukpo Markurdi, (North Central Nigeria), (c) Enugu – Awka - Onitsha road (Eastern Nigeria)

Source <https://naijauto.com/safe-driving/7-most-deadly-roads-to-travel-in-nigeria-15>

Geotechnical, geological, geomorphological, road usage, construction inadequacies, design and maintenance are factors listed by Ebuzoeme [8] that may be responsible for road failure in Nigeria. Adegoke and Agada [9], Mesida [10], and Ajayi [11] from their research works stated that inadequate knowledge of the geotechnical and geomorphological characteristics of residual soils on which roads are constructed play a major role in road failures. Therefore, the objective of this paper was to collate information (location, geotechnical and mineralogical properties) on some residual soils used for road construction or on which roads were constructed upon in selected parts of Nigeria; The collected data were compared to standards specified in the Nigerian specification for road and bridges in order to investigate how these properties have contributed to various road failures.

2. Residual Soils In Nigeria

Laterite soils, lateritic soil, non-lateritic soil, Black cotton soils, Sand-clay soils, Shale, and Sand-clay soils are common types of residual soils found in Nigeria.

Laterites, lateritic and non-lateritic soils are also referred to as tropical red soils [12]. These soils are formed from the intense chemical weathering of crystalline rocks [13]. This crystalline rock is underlain to about 60 % of Nigeria's basement complex [14]. They occur in tropical climate regions of Nigeria [13]. SiO_2 , Al_2O_3 , and Fe_2O_3 constitute over 85 % of the oxide constituents of these soils [15]. For a soil to be referred to as laterite, the molecular ratio of silica (SiO_2) to sesquioxides (Fe_2O_3 and Al_2O_3) would be below 1.33, for lateritic soils, the molecular ratio is between 1.33 and 2.0. while for non-lateritic soils, their molecular ratio is greater than 2.0 [16]. Due to their Fe_2O_3 content, these soils exhibit reddish-brown colouration [15].

Black cotton soils are soils that occur widely in north-western and eastern Nigeria. They occupy an estimated area of 104,000 km^2 [17]. Black cotton soils are formed under conditions of poor drainage from basic rocks or limestone under alternating wet or dry climatic conditions [18]. They have a characteristic of swelling when wet and shrinking when dry due to the presence of a clay mineral known as montmorillonite [19]. In the northern part of Nigeria, apart from black cotton soil, felspathic sandstone, sandy clays, shale, calcareous sandstone, and shelly limestone are also present in significant quantities [20].

Sand-clay soils occur in Benin and Delta states in the South-South region of Nigeria. Delta sands are yellowish-brown ferritic soils and can be divided into reddish-yellow delta sands and silty brownish-grey delta sand [20].

In Eastern Nigeria, the largest group of residual soils occurs as laterites and coastal sands [20]. Shale is said to be the most abundant soil type in Abakiliki, the capital of present-day Ebonyi State, southeastern Nigeria [3]. Peat and organic clays are found in coastal lagoons and channels of Lagos, Niger delta, Niger, and Benue rivers [3]. In the South-Western parts of Nigeria, sandy and clayey soils are present in abundant quantities in parts of Ibadan, Ilorin, Ogbomosho, Ifo, Otta, Ikeja, Ijebu Ode, Ipetu and Abeokuta [20].

2.1 Some geotechnical and mineralogical properties of residual soils along failed sections of selected roads in Nigeria in comparison to Nigerian standards

Table 1. gives the specified and acceptable standards values stipulated by the Nigerian specifications for roads and bridges [2] for the various geotechnical properties of any soil to be used as an embankment, sub-base, and base course material respectively.

Table 1. Specified and acceptable standards values stipulated by the Nigerian specifications for roads and bridges for the construction of roads

Properties of the materials	Nigerian Specification
General filling and embankment	
Passing no. 200 (%)	≤ 35
MDD (Mg/m^3)	> 0.047
moisture content, OMC (%)	< 18
Liquid limit, LL (%)	< 40
Plastic index (%)	< 20
Soaked CBR at British standard (%)	> 5
Sub-base course	
Liquid Limit, LL (%)	< 30
Plastic index (%)	< 12
CBR at west African standard (%)	≥ 30
(%) and OMC (%)	
Base course	
Liquid Limit LL (%)	≤ 30
Plastic index (%)	≤ 12
Unsoaked CBR at modified AAHTO and OMC (%)	≥ 80

Extracted from Maduka et al. [24]

Table 2 gives the geotechnical properties of soils along various failed portions from selected research works in Nigeria. These properties were compared to the stipulated standards in table 1, where the requirements for embankment materials were used to obtain the percentage suitable for road construction.

Table 2: Geotechnical properties of soil samples collected along failed sections of selected roads in Nigeria in comparison to Nigerian standards

S/N	No of samples collected	Geotechnical property	Range	% suitable for road construction (%)	Type of residual soil	Name of road in Nigeria	Reference
1	6	LL (%)	43 – 60.5	0	Inorganic clays	F209 highway at Ado-Ekiti, south-western Nigeria	Jegede [21]
		PI (%)	26.51 – 40.50	0			
		MDD (Mg/m^3)	1.85 – 1.985	100			
		OMC (%)	15 – 17	100			
2	25	LL (%)	20.1 – 55.1	56	Low plasticity clays	Ipele–Isua Highway	Daramola, Malomo and Asiwaju-Bello [22]
		PI (%)	5.2 – 21.96	84			
		MDD (Mg/m^3)	1.51 – 1.792	100			
		OMC (%)	12 – 23	84			

		CBR (soaked)	3 – 17	36			
		% passing sieve 200	11.2 – 86.4	30			
		LL (%)	32.37 – 75	16.7			
3	12	PI (%)	9.63 – 23.53	40	Laterite	Osogbo-Awo Road, Osun State	Oyelami and Alimi [23]
		MDD (Mg/m ³)	1.32 – 1.83	100			
		OMC (%)	13.01 – 27.98	40			
		CBR (soaked)	6.10 – 12.65	100			
		% passing sieve 200	90 – 92	0			
		LL (%)	55 – 64	0			
		PI (%)	36 – 45	0			
4	10	MDD (Mg/m ³)	1.83 – 1.89	100	Shale	Roads in Abakaliki Ebonyi State	Aghamelu and Okogbare [3]
		OMC (%)	12.0 – 12.5	100			
		CBR (soaked)	10 – 12	100			
		% passing sieve 200	7 – 82	81.5			
		LL (%)	29 – 60	0			
		PI (%)	5 – 39	81.5	SM-SC (silty/clayey sand) and high plasticity clay	Nsukka-Adoru-Idah highway, Southeastern Nigeria	Maduka et al [24]
5	27	MDD (Mg/m ³)	15.8 – 2.1	100			
		OMC (%)	13.8 – 18	96.3			
		CBR (soaked)	37 – 74	100			
		% passing sieve 200	17.7 – 47	33.3			
		LL (%)	26.9 – 52.4	44.4	Gravelly clay of low Plasticity to high plasticity clay	A proposed road linking Ipinsa Town in Akure	Adiat Akinlalu and Adegoroye [25]
6	9	PI (%)	5 – 31.1	55.6			
		% passing sieve 200	33 – 51	33.3			
		LL (%)	0 – 45.9	54.2			
		PI (%)	0 – 31.61	79.2			
7	24	MDD (Mg/m ³)	1.497 – 1.982	100	NA	Akungba-Ikare Road	Olubanjo et al [26]
		OMC (%)	5.0 – 11.7	100			
		CBR (soaked)	NA	NA			
		% passing sieve 200	NA	NA			
8	16	% passing sieve 200	NA	NA	NA	Lagos-Ibadan Expressway	Odufa [27]
		LL (%)	6 – 55	37.5			

		PI (%)	13 – 26	43.8			
		MDD (Mg/m ³)	1.55 – 1.98	100			
		OMC (%)	8.3 – 20.3	75			
		CBR (soaked)	2 – 16	81.25			
		% passing sieve 200	23.7 – 59.9	33.33			
		LL (%)	20.6 – 55.5	20			
		PI (%)	10 – 34	5			
9	20	MDD (Mg/m ³)	1.56 – 2.1	100	NA	A road linking eastern part of Ekiti State to the northern part of Ondo State	Alo and Oni [28]
		OMC (%)	NA	NA			
		CBR (soaked)	0.5 - 7.52	15			
		% passing sieve 200	NA	NA			
		LL (%)	17.8 – 32.4	100			
		PI (%)	15.33 – 16.63	100			
10	3	MDD (Mg/m ³)	2.06 – 2.13	100	Clayey gravel	Umuahia- Okigwe expressway Nigeria	Arinze and Obiorah [29]
		OMC (%)	10.0 – 18.21	66.7			
		CBR (soaked)	3 – 4	0			
		% passing sieve 200	32.1 – 62.0	10			
		LL (%)	31.1 – 53.6	20			
		PI (%)	10.1 – 42	20			
11	10	MDD (Mg/m ³)	1.483 – 1.78	100	Low plasticity clay to high plasticity clay	Ogbagi - Akoko road, Southwestern, Nigeria	Thompson, Zaiid and Raymond [30]
		OMC (%)	13.1 – 26	50			
		CBR (soaked)	ND	ND			
		% passing sieve 200	16.38 – 37	71.4			
		LL (%)	38.8 – 49	14.3			
		PI (%)	7.4 – 24.9	57.1			
12	28	MDD (Mg/m ³)	1.89 – 2.89	100	Lateritic soil	Kajola – Oda road South western Nigeria	Ademila [31]
		OMC (%)	8.1 – 15.5	100			
		CBR (soaked)	3 – 23	85.7			
		% passing sieve 200	13 – 58.1	16.6			
13	18	LL (%)	24 – 61	44.5	Clayey soil to granular soils.	Isinbode–Ara road South	Olofinyo, Olabode and

		PI (%)	4.35 – 27.8	50		western	Fatoyinbo
		MDD (Mg/m ³)	1.408 – 2.066	100		Nigeria	[32]
		OMC (%)	11.3 – 30.3	33.33			
		CBR (soaked)	3 – 44	88.9			
		% passing sieve 200	0 – 56.8	80			
14	24	LL (%)	22.5 – 49.6	79.2	Sandy to clayey gravels	Gombe – Bui road in Northern Nigeria	Mahmoud, Belel and Abba [33]
		PI (%)	3.8 – 21.6	90			
		MDD (Mg/m ³)	1.79 – 2.35	100			
		OMC (%)	6.3 – 14.4	100			
		CBR (soaked)	5.1 – 72.7	100			
		% passing sieve 200	2 – 23	100			
15	11	LL (%)	13.9 – 46.2	72.7	Silty sand to clay sand	Ago-Iwoye – Ilishan road, Southwestern Nigeria	Fatoba, Sanni and Ayantunji [34]
		PI (%)	10.6 – 15.9	100			
		MDD (Mg/m ³)	1.47 – 1.68	100			
		OMC (%)	18.5 – 26.7	0			
		CBR (soaked)	69.6 – 75	100			

NA- not available ND not defined

The geotechnical property values obtained from the reviewed works were compared to standard values needed for soil to be used as an embankment material. It was observed that no soil sample was able to meet up with all the criteria need for it to be used as an embankment material. However, soil samples from Gombe – Bui road and Ago-Iwoye – Ilishan road had very high suitability percentages for all criteria. From observations drawn from table 1, a conclusion can be drawn that road failure observed along these roads are as a result of the poor geotechnical properties of soils used for construction.

2.2 *The place of soil mineralogical composition in road failure*

The type of clay minerals present in the soil at times affects the behaviour of the soil. Kaolinite is a type of clay mineral which, when present in the soil, enables it to shrink moderately when dry and expand modestly when wet [35]. Montmorillonite is another type of clay mineral with an expanding lattice [19], i.e., it expands considerably when wet and contracts when dry. This characteristic has always been a problem for engineers when constructing on soils that have this clay mineral present in them [36]. Montmorillonite is the predominant clay mineral found in Abakiliki shale [3], making it a problem soil for road construction. Ugbo-Odogu and Gariki Shale in Anambra state are predominantly composed of kaolinite clay mineral with a mean percentage composition of 44.69 and 25.85 % respectively [37] therefore, they are presumed more stable. The dominant clay mineral found in soil samples obtained from failed sections in Someke, Makelu, and Ikereku areas along Sagamu – Papalanto road, Ogun State is Kaolinite (27.97, 18.75 and 31.53 % respectively). These samples also have a high quartz content of 51.18, 61.73 and 61.38 %, respectively. Other forms of clay minerals found in the soil samples are labradorite and haematite [12]. Most research works reviewed left out the mineralogical investigation to determine the type of clay mineral present in soil samples that they collected. This common observation leads to the conclusion that researchers are giving less importance to this factor when they investigate reasons for road failures.

3. Researchers views on the course road failures on selected roads in Nigeria

3.1 *Roads in Abakaliki Southeastern Nigeria*

Aghamelu and Okogbare [3] in their research work were of the opinion that roads in Abakiliki would keep failing because contractors and engineers are sometimes left with no other option than to construct using Abakaliki shale due to its abundance and the high cost of haulage of suitable material during construction. Results obtained from their research work (table 2) show that this residual soil type is not suitable for any form of pavement construction, hence reasons for road failures experienced in this region.

3.2 *Onitsha-Enugu Expressway, and Port Harcourt – Enugu Expressway, Southeastern Nigeria*

The Enugu-Onitsha expressway is very important in Nigeria because it connects the South East and South-South, through the Niger Bridge, linking Anambra, Enugu and Ebonyi States, as well as the North, via Benue and Kogi States. Onuoha, Onwuka, and Obienusi [38] in their research work stated that the inadequate maintenance of Onitsha-Enugu expressway, mismanagement of the road by the Nigerian government and old age of the road are major reasons for the continuous failure of this road. But in another work [39] carried out by them on the same road, they observed that geotechnical properties of soil samples collected from failed sections along the road did not meet up to standards, thus contributes to the failure of this road.

The Port Harcourt – Enugu Expressway is another very important expressway in Nigeria because it connects Port Harcourt through Aba to Okigwe to Enugu. Tse and Efobo [40] listed the possible reasons for the reoccurring failure of this road as; poor quality of soils used as sub-grade materials, presence of shales of low permeability, and the presence of montmorillonite in the soil samples obtained from failed sections.

3.3 Lagos – Ibadan Expressway Southwestern Nigeria

One of the busiest major highways in south-western Nigeria is the Lagos – Ibadan expressway. Although a large number of resources are being expended on the rehabilitation and reconstruction of this road, it usually fails shortly after, with characteristics of potholes, cracks, ruts, depressions, and it has become a source of an economic drain to the country [41, 42]. Layade, Adegoke, and Oyewole [43] in their research work said that the presence of fractured bedrock, clay, and sandy-clay soil with high permeability and porosity along the Lagos – Ibadan expressway are possible reasons for constant failures experienced along this road. The geotechnical investigation by Odunfa et al. [27], on the soil properties along the failed sections of the expressway (table 2) showed that, of the 16 soil samples collected along the failed sections of the road, only 81.25 % were suitable for construction of embankments based on the CBR criteria. 93.8 % of the soil samples were not ideal for the construction of either base course, sub-base course, or embankment based on the plasticity index criteria. They concluded from their findings that prior to the commencement of the road project, there was no adequate investigation on the properties of the subbase and base course material hence the frequent occurrence of road failure. Faults and clayey subgrade were also discovered along the expressway when a geophysical investigation was carried out [44], which are also possible reasons for the reoccurrence of failures along the road.

3.4 Ibadan–Ife Expressway Southwestern Nigeria and Selected Highways in Ifelodun Local Government, Ikirun-Osun

Ibadan – Ife expressway, a continuation of the Lagos – Ibadan expressway, aids in the movement of goods and services from the southwest to the northern parts of Nigeria. Typical to most highways in Nigeria, the road was observed to have failed just a few years after construction [45]. Table 3 gives the geotechnical properties of 8 soil samples collected along the road

Table 3: Geotechnical properties of soil samples collected along failed sections of Ibadan–Ife Expressway, South-Western Nigeria in comparison to Nigerian standards

S/N	No of samples collected	Geotechnical property	Range	% suitable for road construction (%)	Type of residual soil	Name of road in Nigeria	Reference
1	8	% passing sieve 200	25.42 – 82.94	25	Inorganic clays	Ibadan–Ife Expressway, South-Western Nigeria	Bello and Atilola [46]
		LL (%)	23.69 – 48.3	37.5			
		PI (%)	4.75 – 23.65	37.5			
		MDD (Mg/m ³)	1.81 – 2.76	100			
		OMC (%)	9.6 – 15.4	100			
		CBR (soaked)	9.85 – 21.61	0			

A close comparison with standard values stipulated for sub-base course material shows that only 37.5 % of the soil samples were suitable for base course construction based on the liquid limit and

plastic limit criteria. None of the soil samples had bearing capacity carry load as 0 % met up to the standard value of ≥ 30 CBR value for sub-base materials. These poor geotechnical properties of the soil samples are possible reasons why this road experiences road failures.

3.5 Osogbo-Iwo Expressway, Takie – Ikoyi Road, Akure – Ijare – Owo Expressway, Akungba – Ikare road and Igbara – Oke – Ibuji road in Southwestern Nigeria

Aderinola, Ola, and Owolabi [47] collected 15 samples from failed sections along Osogbo – Iwo expressway. Their results obtained showed that most of the soil samples did not meet up to standards for sub-grade and base course construction, hence a possible reason for the failure of the road. Adagunodo, Summonu, and Oladejo [48] carried out an electromagnetic investigation on Takie – Ikoyi road located at the heart of Ogbomoso. They observed the presence of clay minerals below the road surface, which they gave as a possible reason the road fails. Another geophysical investigation was carried out along Akure – Ijare road by Falowo, and Akintorinwa, [49], where they also observed the presence of clayey materials at the topsoil and subsoil at the failed sections. The presence of expansive clays (a typical feature of montmorillonite clay mineral) at failed sections along Akure – Owo expressway was also observed during a geophysical investigation of the road, by Adeyemo and Omosuyi [50]. These clay minerals are not good for road construction as they expand when wet and contract when dry hence resulting in the damage of the road pavements. Clayey subgrade soil within the upper layer of the road, faults, fractured zones, and fissures are reasons listed by Mohammed [51] as reasons for road failures observed along Akungba – Akoko highway. Table 2 shows the poor geotechnical properties of soil samples obtained along Igbara – Oke – Ibuji, which have already been stated as the possible reasons for failure along that road.

3.6 Opoji – Uwenlenbo – Illeh road and Shagamu – Benin Expressway

Construction over clays [52]: Opoji, Uwenlenbo, and Illeh road; buried features such as buried stream channel and shear zone beneath the road [53], low CBR [54, 55]: Shagamu – Benin expressway; areas of low permeability clay [56, 57]: Irrua to Opoji in Edo State, are reasons given for failures experienced along these roads.

3.7 Okitipupa – Igbokoda Highway, Ado - Ajebandele - Ikere Road and Ado – Ekiti – Ilewa – Ogbagi – Ekiti Road in Southwestern Nigeria

Low CBR values which resulted in the incursion of surface water into the base course [58], the presence of excess fines [59]: Okitipupa – Igbokoda highway; poor geotechnical properties such as the soils CBR values, liquid limit, Plasticity index, and percentage of soil passing through sieve number 200, [60, 61, 62]: Ado – Ajebandele – Ikere road; low permeability value resulting in the soils high ability to retain water [63, 64] - Ado – Ekiti - Ilewa – Ekiti road in Ekiti State, are reasons given for failures experienced along these roads.

4. Conclusion

From most research works reviewed, mineralogical investigation to determine the type of clay mineral present in soil samples collected was not carried out. This implies that less importance is put to the kind of clay mineral present when investigating reasons for road failures in Nigeria. Soil samples collected from failed sections along some investigated roads in Nigeria showed that most

of the soils used for constructing the roads, or on which the roads were constructed, did not meet up with standard specified values by the Nigerian Specification for road materials.

Other views of some researchers on reasons why roads fail includes; the mismanagement of the road by the Nigerian government, construction over clays and buried features such as stream channels, shear zone beneath the road, low permeability value, and incursion of surface water into the base course

Reviews also showed that majority of research works were concentrated in the south-western and southeastern parts of the country. Fewer works are readily available on investigations into reasons for failed roads in the Northern parts of the country thereby raising research questions such as;

1. Do roads fail more in the southern, western, and eastern regions compare to the northern regions?
2. Are standards enforced more in the northern parts compared to other parts of Nigeria?

From these reviews, it was observed that the major reason why roads fail in Nigeria is due to the fact that soils used for construction do not meet up to standards. Therefore, to ensure that more durable roads are constructed, checks should be properly put in place and adhered to in order to ensure that these standards are followed strictly during road constructions in Nigeria.

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