ENGINEERING BEHAVIOUR AND THE ENHANCED STRENGTH PERFORMANCE OF STRUCTURAL FRAMEWORKS IN SOUTHWESTERN NIGERIA USING AN INDUSTRIAL WASTE

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Abstract: Proper design of engineering structural framework begins from improving the characteristic of soils. This is due to undesirable behaviour of subgrade soils such as dispersion, swelling, shrinking and high level of settlement. Several strategies such as mechanical and chemical additives are considered to be an effective technique for soil improvement. An industrial waste is prescribed to improve the mechanical strength property and compressibility of engineering structural framework when subjected to heavy loads with little or zero cost. Disturbed and undisturbed soils (A1, A2, B1, B2, S1 and S2) were acquired using digger, shovel and core cutter, respectively. Disturbed samples were subjected to classification tests such as grain size distribution and consistency limits while California Bearing Ratio and Unconfined Compressive Strength. These soils were examined and interpreted with Landsat Image. The results (A1, A2, B1, B2, S1) show good to excellent materials, low plasticity and swelling potential , high maximum dry density , low moisture content and *high compressive strength* while structural deformation indicating good engineering and geological properties of subgrade soils utilized for construction purposes. S2 results shows high amount of fines, show fair materials, high plasticity, display critical expansive properties, low maximum dry density, high optimum moisture and low *compressive strength* than the minimum acceptable values of 103 kN/m^2. It was inferred from 0 to 25% percentage addition of quarry dust stabilizer that plasticity index, liquid limit, OMC and plastic limit decreases with increasing in quarry dust while UCS and MDD is increasing with an increase in percentage of Quarry Dust. There is an increase in mechanical strength with percentage addition of industrial waste; thuss serving as suitable alternatives to modify and stabilize structural deformations.
Keywords: Soil indices, structural systems, stabilization, quarry dust, strength

Introduction

The Engineering structural frameworks are seriously threatened as a result of pavement distress. Pavement is the strong surface material set down on an area intended to sustain vehicular traffic such as a road or walkway. It is vital to motorists and road users. It has enormously added, not only to the socio-economic development of the area which it links, but also to the country as a whole, it helps in the movement of people, rural items and merchandise (Adewoye *et al.,* 2004). Pavement is of two types; flexible pavement and rigid pavement. Flexible pavements are those sections which can't withstand the considerable ductile pressure, while, rigid pavements are those road roads covering which can withstand appreciable tensile stress (Adewoye and Adeyemi, 2004). A road pavement is supposed to be a continuous stretch of asphalt lay for smooth ride or drive but visible cracks, potholes, bulges and depression punctuates such smooth drive leading to failure of flexible highway pavement. This is a typical in most parts of the tropical world. Such failures can occur in form of pitting, rutting and waviness (Gidigasu, 1972).

There are numerous factors that can influence the performance of highway pavement structure. These include: geo-morphological, geo-technical, design, material selection, construction practices, maintenance, usage factor and geological structures like fractures or lineaments observed through satellite imagery (Akintorinwa *et al.,* 2011). Satellite imagery is being utilized for the mapping of highways pavement failures. This is a direct result of its ease operation, velocity, accuracy, coverage and low cost. Soil stabilization is then the process by which soil properties are improved for construction purpose through after; increases in soil strength, resistance to deformation and durability, reductions in swelling potential or/and other desirable characteristics, such as dust and water proofing unsealed roads (Oyediran *et al.,* 2011). The technique of soil stabilization is typically adopted with translating plastic soils to the standards of engineering projects. A variety of ground improvement technique have been created and effectively applied in several areas. The selection of appropriate ground improvement strategy relies upon the soil that is to be treated, the accessibility of materials required and viability of economic. Currently, various sorts of materials like lime, cement, fly ash are used.

As indicated by Oyediran and Kalejaye (2011), soil properties are improved and made progressively appropriate for construction purpose through mechanical, chemical and in some cases organic methods. In this research, sub-grade soils were examined and further analysed, a significantly deformed soils were stabilized with industrial waste known as quarry dust. Quarry dust is bye-product acquired during crushing at quarrying sites to obtain aggregates. Quarry dust shows high shear strength which is exceptionally valuable for its use as a geotechnical material Soosan *et al*. (2001). Quarry dust can be used as a substitute for sand to improve the properties of lateritic soil Soosan *et al*. (2005). Quarry dusts are considered as one of the financially savvy ground improvement technique for weak soil deposits. It consists mainly of excess fines generated from crushing, washing and screening operations at quarries. The aim of the research is to determine the geo-technical properties and geological highlights using landsat imagery on the pavement failure of the Ogbomoso – Ilorin Road with the view of treating the failed portions with a low cost materials.

Materials and Methods

Description of study area

The study area is located along Ogbomosho-Ilorin road on latitude 8˚ 26′ N, to 8˚ 9′ N and longitude 4˚ 13ᴵ E to 4º 24ᴵ E. The road trends on NNE – SSW with Ilorin in the north and Ogbomosho to the south. The study area is relatively rugged with undulating topography. The average elevation above sea level is about 314 m. The study area is low lying (low relief) and has a dendritic drainage pattern which is controlled by the topography. The study area experiences tropical rainfall which has two distinct seasons, the wet season usually between March and October, and the dry season which falls between November and February every year. The annual rainfall is 1247 mm, but the amount varies from 1016 to 1524 mm. The vegetation of this area is that of the rainforest and derived savannah. The study area lies on the basement Complex area of southwestern Nigeria, comprising undifferentiated Gneiss – migmatite complex (Oyawoye, 1972). Rock exposures include migmatitegneiss, banded gneiss, quartzite and porphyritic granite (Fig. 1).

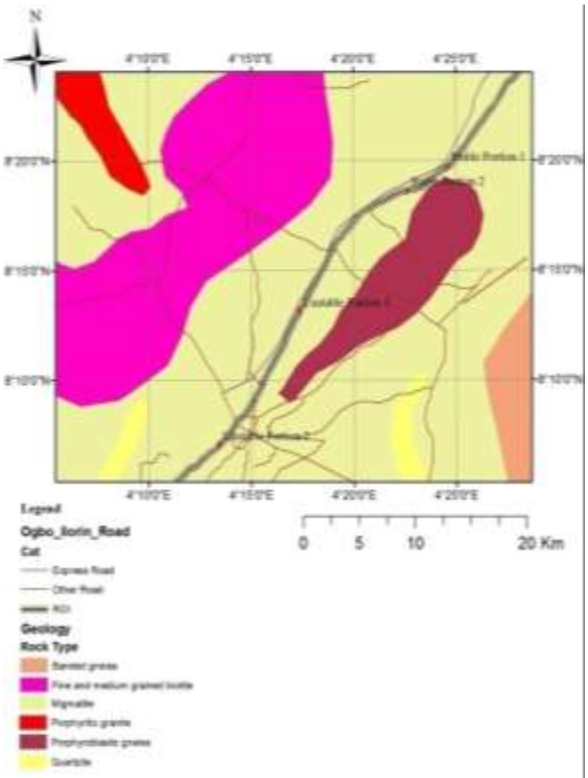

Fig. 1: Geologic map of the study area showing the Road of Interest (NGSA, 2006)

Migmatite gneiss is the most widespread group of rock and forms the background in which all other basement rock seems to occur. The minor rock is pegmatite. The Petrographic analysis was basically used to determine the detailed texture and mineralogical characteristics of the rock samples in relation to the derived soils. The modal analysis were studied accordingly to identify various mineral components of rock samples especially their clay mineral content in engineering test. The major minerals observed in the rock are quartz, plagioclase feldspars and micas. The summary of the modal analyses of minerals present in the thin section of rock samples are shown in Table 1.

Methodology

The research was carried out in two major stages:- field investigation and laboratory analysis. Field investigation includes; sample collection, description and preparation. To access the highway pavement effectively, six samples were collected .Undisturbed samples were taken with the aid core cutter (three failed and three unfailed locations). The disturbed sample were collected with the aid of digger, hand shovel and head pan from trial pit and air dried for three weeks at room temperature before laboratory analysis commenced. Interpretation of Landsat Image and resulting enhanced image was revealed through the lineaments in the study area which were digitized using Acrview GIS 10.4 computer software. A total number of 175 lineaments were generated through an Azimuth- Frequency diagram (Rose Diagram). The main laboratory test carried out on the disturbed soil samples were; specific gravity, grain size distribution, Atterberg limits, california bearing ratio, unconfined compressive strength and compaction. All these tests were carried in accordance with (British Standard, 1975). The geotechnical results were interpreted and subjected to stabilization with addition of quarry dust in varying proportions so as to improve the geotechnical properties.

Results and Discussion

Remote sensing and Gis

A lineament is a linear feature in a landscape which is an expression of an underlying geological structure such as fractures, joints, fault, folds. Fig. 2 shows the Enhanced Landsat ETM + Band 7 image of Ogbomoso – Ilorin area; while Fig. 3 shows the lineament map of Ogbomoso – Ilorin area. The study area is criss-crossed with lineaments consequent to a number of tectonic activities in the past. Some linear features are suspected to be be fracture and fissure zones as displayed in the rose diagram, Four prominent structural trends identified are (N-S, NNE-SSW, NW-SE, and E-W) that are typical of the Nigeria basement complex are represented in the study area. Usually, lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the presence of lineaments usually denotes a fractured zone. Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas underlain by migmatite gneiss having relatively lower lineament density. There are several linear features that cut across the studied area and most especially around and within the unstable pavement of the highway. Hence, it is suspected that the possible cause of the failure in the structural systems, since linear fracture are characteristics of weakness zones. A lower weightage was assigned to areas with low density of lineaments, which are closely associated with area underlain by migmatite. Rose diagram is a circular diagram from plotting strikes (with or without dips) of planar features, joint, faults and dikes; so named because clusters of preferred orientations resemble the petals of a rose (Fig. 4).

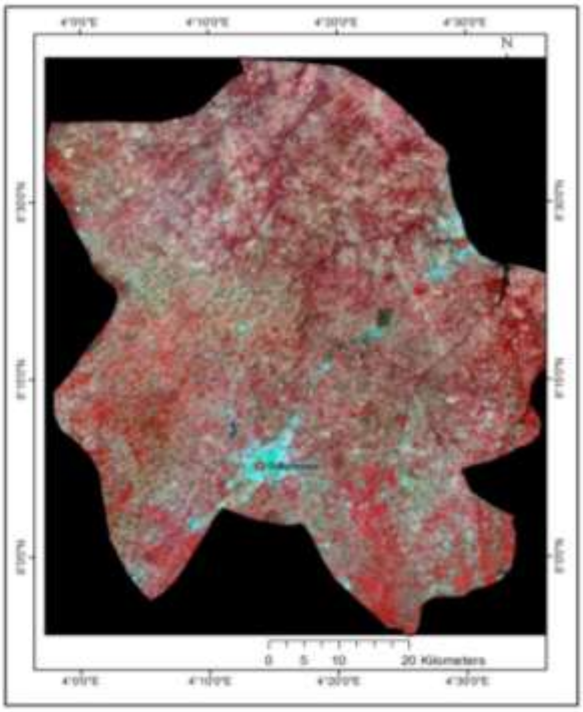

Fig. 2: Enhanced landsat ETM + Band 7 of Ogbomoso – Ilorin highway area

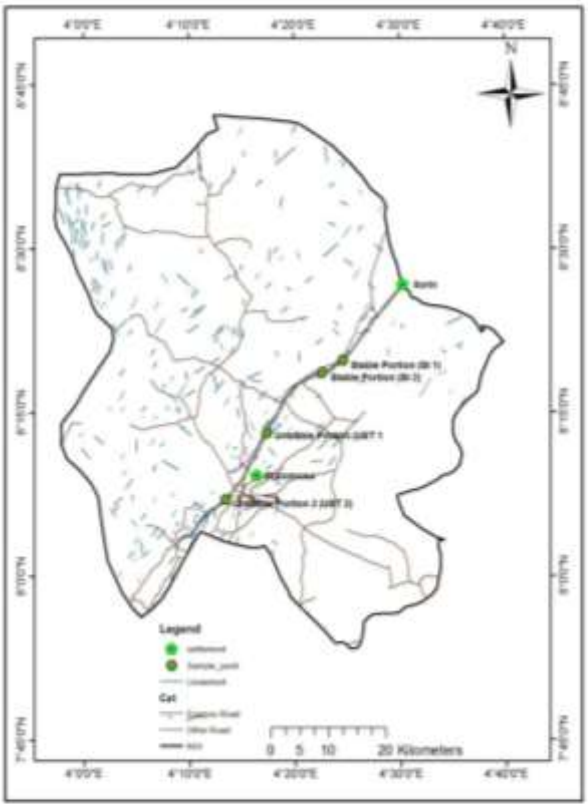

Fig. 3: Lineament map of the study area

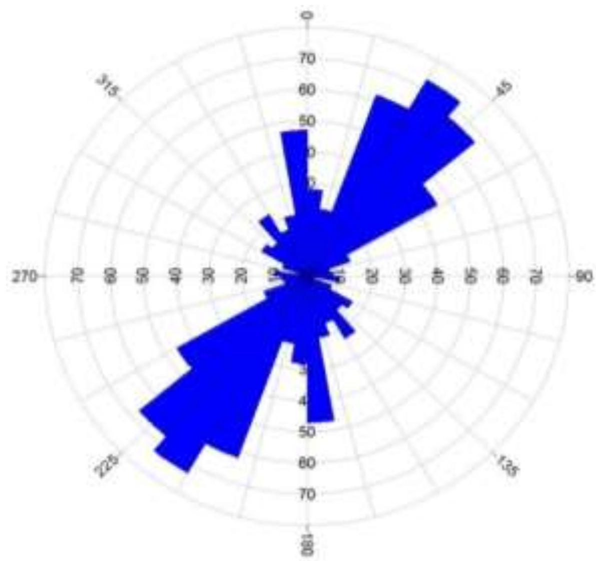

Fig. 4: Rose diagram of the lineament of the study area

Geotechnical studies

The results of the geotechnical tests carried out on samples taken from six different locations of the highway are presented in Table 1. It was recorded from the modal analysis that the local geology is made up of the major minerals such as quartz, plagioclase feldspars and micas (Adewoye *et al*., 2017). Rocks rich in quartz will weather to predominantly coarse-grained minerals (sand and gravel) particles abundance of feldspar will lead to fine-grained clay soils while abundance of mica will produce soils that are rich in silt-size particles (Gidigasu, 1976; Adeyemi and Oyeyemi, 2001). The tests are grain size distribution, specific gravity of grains, consistency limits, compaction, California Bearing Ratio, unconfined compressive strength and permeability. The grading curves of the studied soils are shown (Fig. 5 and Table 1). The study soil are well graded on the basis of wide grian-size distribution spectrum. They are all classified has granular as they fall in a-1-b, a-1-a, and a-2-4 with the exception of test S2 that falls in a-7-6 subgroup of AASHTO classification system. The general rating of the study is excellent to good subgrade materials under the AASHTO Classification system except S_2 which is fair to good. The percentage of fines observed in the study area ranges from minimum to maximum 15 to 46%. The percentage of fines in every one of these areas is higher than required 15% maximum value. Studied soils A_1, A_2, B_1, B_2, S_1, and S_2 had lower percentage of fines exhibiting better engineering characteristic.

The lower the percentage of fines, the better the engineering characteristic (Adewoye *et al*., 2004; Adewoye and Adeyemi, 2004). Higher percentage of fines in studied soil S_2 make it unacceptable as base course/sub-base and subgrade and are even attributed to the poor engineering quality of same. Specific gravity of any soil is important property that evaluates the aggregate parameters for construction purposes and assess the degree of weathering (Gidigasu, 1976). The specific gravity values of the soil sample ranges from 2.50-2.75 for all studied samples, the average values of the specific gravity are within the same range Table 1. Essentially, all the values of the studied soils are greater than 2.50. Akroyd (1963) had recommended the utilization of specific gravity in assessing the maturity of lateritic soils. The specific gravity of laterite soils is an indication of the degree of laterization. The specific gravity of soil A1, A2, B1, B2, and S1 are greater than studied soil S2. None of the soils display specific gravity characteristic of organic soils. The higher the specific gravity of a soil and the degree of laterization, the stronger the soil would be.

The results of the studied soils shows that the liquid limit lies between 27 – 55% while the plastic limit ranges from 20 – 32% and the plasticity index from 6 – 22% (Table 1). The liquid limit of the studied sample S2 is relatively high compared to a minimum of 30% and maximum of 40% stipulated by the Federal Ministry of Works and Housing (FMWH, 1995) as subgrade materials. All the study soil sample falls within the specifications thus making all suitable for sub- base materials except studied soil S_2 that has 55% maximum for limit liquid. However, the soils with liquid limit higher than 40% will be poor sub-grade and sub-base materials. The plasticity index is a measure of the affinity of the soil for water. However the Federal Ministry of Works and Housing (1995) specified a maximum plasticity index of 20% for highway subgrade material. None of the soils have plasticity index in excess of 35% except S2 and are thus not likely to suffer excessive shrinkage except same. The high value indicated in S2 may show poor engineering properties which may often lead to waviness a type of road failure caused by unduly compress under heavy load. The studied soils A_1, A_2, B_1, B_2, S_1 plot within the field of inorganic clay of low plasticity and swelling potential indicating poor engineering and geotechnical properties of subgrade soils (Jegede, 1995). Studied soil S_2 plots within the field of high plasticity (Casagrande, 1948); it can be deduced that studied soil S2 exhibit high swelling potential and display critical expansive properties (Fig. 6). Soils that plot below A – Line have proved problematic when soils are used for construction purposes (Adewoye & Adeyemi, 2004).

Table 1: Index properties of the studied soil

Sample Code	State of Pavement	Specific Gravity	Size Distribution Consistency (%) Clay	(%) Fines	Plasticity Index	Liquid Limit	Plastic Limit	State of Plasticity	AASHTO	General Rating
A1	Stable	2.65	12	17	6	29	23	Low	A-1-b	Excellent to Good
A2	Stable	2.60	20	27	8	29	21	Low	A-2-4	
B1	Stable	2.67	17	25	7	27	20	Low	A-1-b	
B2	Stable	2.67	5	15	6	30	24	Low	A-1-a	
S1	Stable	2.75	13	20	8	30	22	Low	A-2-4	
S2	Unstable	2.50	31	46	22	55	32	High	A-7-6	Fair to good

AASHTO: American Association of state Highways and Transportation Official

Table 2: Strength properties of the studied soils

Sample Code	State of Pavement	Compaction: Maximum dry density (MDD) (%)	Optimum moisture content (OMC) (%)	UCS	Unsoaked CBR	Soaked CBR
A1	Stable	1860	10	151	25	6
A2	Stable	2003	11	166	23	8
B1	Stable	1920	12	176	29	10
B2	Stable	1900	13	196	22	9
S1	Stable	2060	10.5	112	30	7
S2	Unstable	16040	18.7	92	40	15

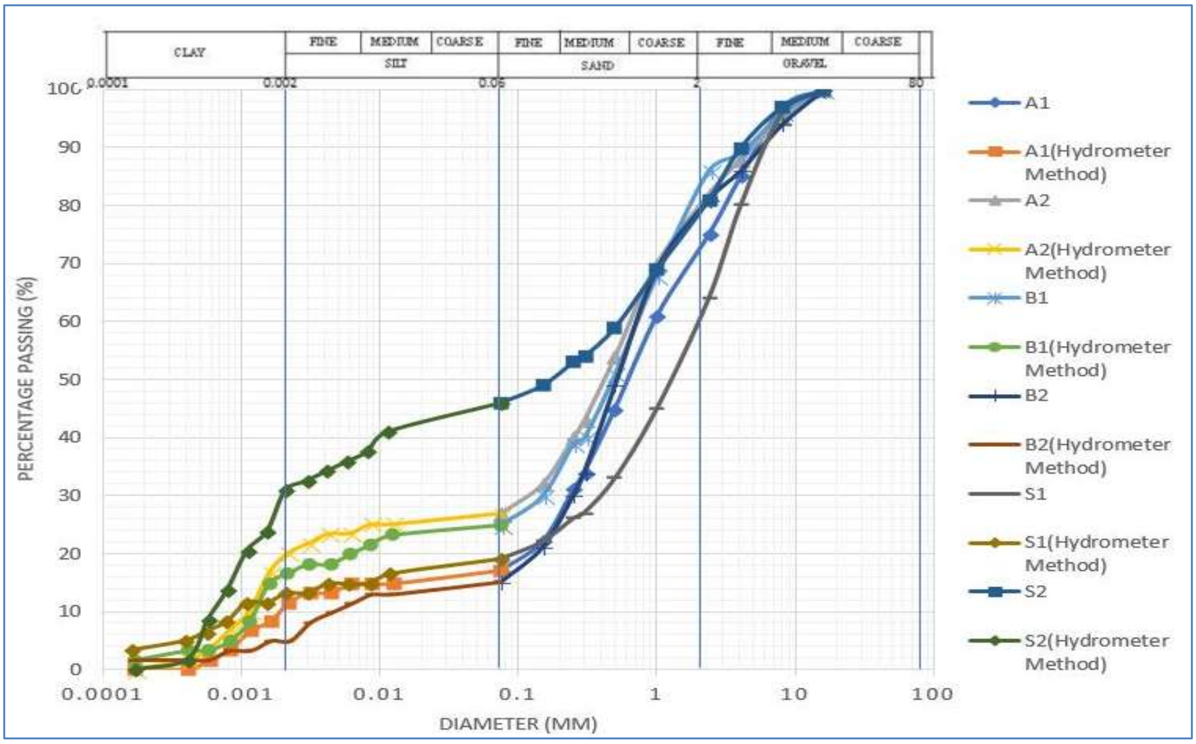

Fig. 5: Grain size distribution graph for A1, A2, B1, B2, S1 and S2

The importance of compaction test is to improve the desirable load bearing capacity properties of a soil as a subgrade, subbase soils and the base course material for use in pavement design (Liu and Evett, 1998). The result of the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD) obtained are listed (Table 2). The optimum moisture content (OMC) for the soils range between 10 to 18.7% (Fig. 7 and Table 2). The result of maximum dry density (MDD) for the studied soil ranges from 1640 to 2060 kg/m^3 for modified AASHTO level of compaction Fig. 7. Bello *et al*. (2007) opined that samples characterized with high value of maximum dry density and low optimum moisture content is best suitable as sub base and sub grade materials. The Studied soil samples A1, A2, B1, B2 and S1 are with high maximum dry density and with low moisture content shows more strength for foundation and construction works. However studied soil S2 has lower maximum dry density and higher optimum moisture content than A1, A2, B1, B2 and S1 studied soil .This may be attributed to its higher water affinity and greater swelling potential. Based on these specifications samples S2 are not suitable as sub base and subgrade material. The CBR value for the unsoaked samples A1, A2, B1, B2, SI were 25, 23, 29, 22 and 30% while S2 is 40%. The CBR values for the soaked samples A1, A2, B1, B2, SI were 6, 8, 10, 9, and 7% while S2 is 15%, respectively (Table 2). These values are generally less than 30 and 80% recommended for highway sub-base and subgrade soils by the FMWH (1995). They all yielded fair to poor CBR values which could be attributed to ingress of water due to a poor drainage and high amount of clay content making them inadequate for sub-base and sub-grade materials and this consequently would not withstand the loads imposed upon it. With this attributes, the studied soils are considered problematic therefore it is important to improve the mechanical strength properties.

Unconfined compressive tests are used in estimating the bearing capacity of highway subgrade and sub-base materials.

The result of the UCS of the soil studied A1 is 151, A2 is 166, B1 is 176, B2 is 196 and SI is 112 kN/m^2, respectively (Table 2), which are all higher than the minimum acceptable values of 103 kN/m^2 except unstable portion S2 which is 92 kN/m^2 (Ola, 1997). Soils below the Stable locations have higher uncured strength than those below unstable locations. This is due to the fact that the soils below stable locations have better grading characteristics than the soil below unstable locations. Soils below stable locations are to sensitive to curing, that is they have higher percentage increase in strength as a result of curing because they are richer in amount of clay-sized particle than those below unstable locations (Akingbade, 2003). In other words, soils below stable locations have high compressive strength than those soils below unstable locations. The higher the compressive strength, the better the engineering soils.

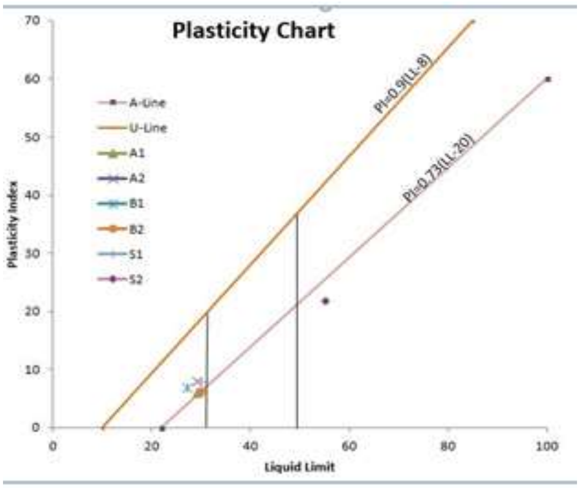

Fig. 6: Cassagrande plot of soils A1, A2, B1, B2, S1 and S2

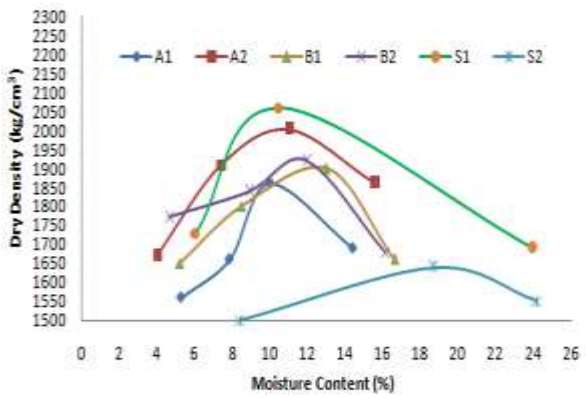

Fig. 7: Compaction test graph for sample A1, A2, B1, B2, S1 and S2

Influence of stabilizer

Soil sample S2 has Optimum Moisture Content (OMC) of 18.7, 15.4, 13.0, 10.8, and 6.0%, respectively with 0, 5, 10, 15 and 20% addition of Quarry dust (Table 3). The OMC decreases from 18.7 to 6.0% as the quarry dust is increased from 0 to 25% (Fig. 8). Soil sample S2 has Maximum Dry Density of 1604, 1840, 2010, 2016 and 2050 kg/cm^3, respectively at 0, 5, 10, 15 and 20% addition of Quarry dust (Table 3). The Soil sample S2 results shows progressive increment in maximum dry density from 1604 to 2050 kg/cm^3 as the Quarry Dust was increased from 0 to 25% (Fig. 9); this agrees with the work of Sabat (2012) and Naganathan *et al.* (2012). The increase in MDD is an indicator of improvement of soil properties and this agrees with the submission of Basha *et al*. (2005) and Ola (1977). According to Amu *et al.* (2011), increment in MDD values with increment in rate of quarry dust being added to lateritic soil demonstrates improvement in Soil properties. Increase in percentage of quarry dust from 0 to 25%, decrease plastic limit from 32 to 20%; Plasticity index from 23 to 6% (Fig. 10) and as shown in Table 3.

Table 3: Strength properties of the failed soils treated with quarry dust

Stablizer	Liquid Limit	Plastic Limit	Plasticity Indexi	Maximum dry density kg/cm^3	Optimum moisture content (%)	Unconfined Compressive strength kN/m^3
0	55	32	23	1604	18.7	92
5	46	31	15	1840	15.4	109
10	37	24	13	2010	13.0	114
15	34	22	12	2016	10.8	152
20	26	20	6	2050	6.0	184

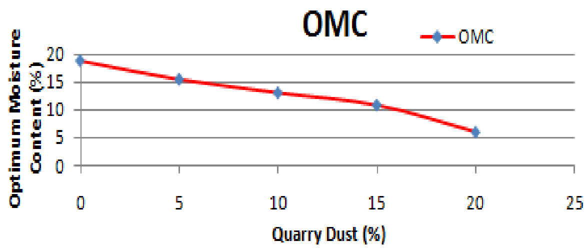

Fig. 8: Variation of optimum moisture content (OMC) with percentage of quarry dust for sample S2

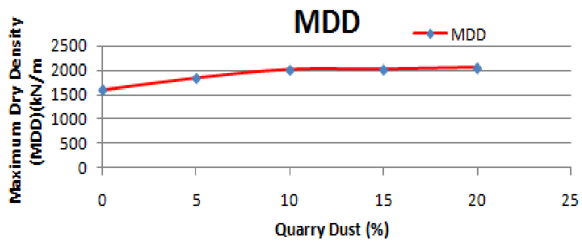

Fig. 9: Variation of maximum dry density (MDD) with percentage of quarry dust for sample S2

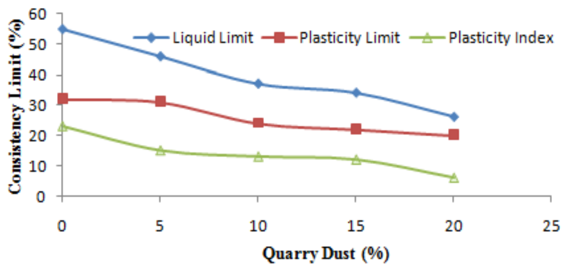

Fig. 10: Variation of consistency limit (LL, PL and PI) with percentage of quarry dust for sample S2

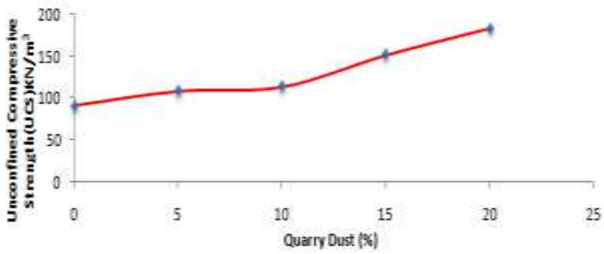

Fig. 11: Variation of unconfined compressive strength (UCS) with percentage of quarry dust

The decrease in plasticity index infers a decrease in swelling features of expansive soil-quarry dust mixes. Consequently, a decrease in plasticity index is an indication of enhancement in the property of soil (Das, 1994). This coincides with the work of Sabat (2012) and Naganathan *et al*. (2012). As also expressed by Jegede (1995), the high plasticity index and liquid limits are indicative of poor engineering and geological properties of sub-grade soils. The plasticity index of the soils indicates soils suitable as sub-grade materials in road construction because they fall below the maximum 25% recommended for sub-grade tropical soils by Simon *et al*. (1973). Soil sample S2 has UCS value of 92 kN/m^2 which is lower at than 103 kN/m^3 as recommended by FMWH (1995). Soil sample S2 had the UCS values of 109, 114, 152 and 184 kN/m^2, respectively when treated with 5, 10, 15 and 20% of quarry dust (Table 3). Soil sample S2 *is increasing with varying increase in the proportion of the quarry dust,* respectively. An highest UCS strength value of 184 kN/m^2 at 20% quarry dust addition was observed. The higher the compressive strength, the better the engineer soil and geotechnical properties of the soil. The result of unconfined compressive strength (UCS) treated with different proportions of quarry dust is shown in Fig. 11.

Conclusion

All studied subgrade soils except S2 are well graded, showed higher specific gravity, possess low percentage fines, granular, fall in a-1-b, a-1-a, and a-2-4 subgroup of AASHTO classification system, have low plasticity and swelling potential, exhibit high maximum dry density and low optimum moisture content and had higher compressive strength giving stronger, better and excellent subgrade materials engineering soils. Studied soils S2 showed high amount of fines, falls in a-7-6 subgroup of AASHTO classification system indicating intermittently shrinking and swelling causing damage to the subgrade, exhibit high swelling potential and display critical expansive properties, has lower maximum dry density and higher optimum moisture content, higher CBR values, lower compressive strength indicating weaker subgrade. It was observed that the studied soil S2 was geotechnically impaired leading to pavement failure. The cause of this failure may be overusage or poor drainage system. Failed soil S2 was treated with different percentages of quarry dust so as to study its effect on consistency limit; MDD; OMC and shear strength. It was inferred from 0 to 25% percentage addition of quarry dust that plasticity index, liquid limit, OMC and plastic limit decreases with increasing in quarry dust while UCS and MDD are increasing with an increase in percentage of Quarry Dust.

Conflict of Interest

Authors declare that there is no conflict of interest reported in this work.

References

Ackroyd LW 1963. The Correlation between engineering and pedological classification system in western Nigeria and its implication. *Reg., Conf. Africa Soil Mechs. Found. Eng* 2nd edition Salisbury, Rhodesia, 1: 115-118.

Adewoye AO & Adeyemi GO 2004. Geotechnical properties of soils along the Lagos – Ibadan Expressway, Nigeria. *J. Res. Inform. in Civil Engr.*, 1(1): 1-10. www.useprice.webs.com.

Adewoye AO, Adegbola AA, Bolaji AA & Opebiyi DF 2004. Engineering properties of foundational materials of Oyo-Ogbomoso Road in Southwestern Nigeria. *Int. J. Bio. and Physical Sci.*, 9: 42 – 47. www.sciencefocus.com.ng

Adewoye AO, Olayinka AI & Abimbola AF 2017. Hydrogeochemical geometry of subsurface layers in Odo-Oba Town, Southwestern Nigeria. *Int. J. Engr. and Techn. IJET-IJENS*, 17(4): 9-24. http://www.ijens.org

Adeyemi GO & Oyeyemi F 2001. Geotechnical basis for failure of sections of the Lagos-Ibadan Expressway, Southwestern Nigeria. *Bull. Engr. Geol. and the Envt*., 59: 39–45.

Akintorinwa *et al*. 2011. Appraisal of the causes of pavement failure along with the Ilesa - Akure Highway, Southwestern Nigeria, using remotely sensed and geotechnical data. *Ife Journal of Science*, 13: 1.

American Association of State Highway and Transportation Officials (AASHTO) 1962. The AASTHO Road Test, Highway Research Board of the NAS-NRC Division of Engineering and Industrial Research, Report 5. *Special Report* 61E, Washington DC., USA, pp: 90-100.

Amu OO, Bamisaye OF & Komolafe IA 2011. The suitability and lime stabilization requirement of some lateritic soil samples as pavement. *Int. J. Pure Appl. Sci. Technol*., 2(1): 29-46.

Basha EA, Hashim R, Mahmud HB and Muntohur AS 2005. Stabilization of residual soil with rice husk ash and cement, construction and building materials, 19, 448 – 453.

Bello AA 2007. Influence of compaction delay on CBR and UCS of cement stabilized lateritic soil. *Pacific J. Sci. and Techn., USA*, 12(2): 87-98.

British Standard Institution 1975. Methods of test for soil for Civil Engineering. BS 1377: *British Standard Institution*, London, p. 80.

Cassagrande A 1948. Classification and identification of soils, transactions. *ASCE*, 113: 901-663.

Das BM 1994. Principles of Geotechnical Engineering 3rd edn, PWS Publishing Co., Boston-Massachusetts, USA.

Federal Ministry of Works and Housing (FMWH) 1995. Highway Manual Part 1 Road Design. Federal Ministry of Works and Housing, Lagos, pp. 45-64.

Gidigasu MD 1972. Review of identification of problem lateritic soils in highway engineering. *Transport Research Board, Washington*, 497: 96-111.

Gidigasu MD 1976. Development of acceptance specification for tropical gravel paving materials. *Engineering Geology*, 19: 213 – 240.

Jegede G 1995. Highway pavement failure induced by soil properties along the F209 highway at Omuoke, Southwestern Nigeria. *Nigeria Journal of Science.*

Liu C & Evett BJ 1998. Soils and Foundations, 4th edition, Prentice-Hall, Inc, United States of America.

Naganathan S, Razak HA & Hamid SNA 2012. Properties of controlled low-strength material made using industrial waste incineration bottom ash and quarry dust. *Materials & Design*, 33: 56 – 63.

Nigerian Geological Survey Agency (NGSA) 2006. *Lineaments Map of Nigeria*. Published by the Authority of the Federal Republic of Nigeria, 2006.

Ola SA 1997. Geotechnical properties and behavior of some Nigerian lateritic Soils. In: Ola SA (ed) Tropical Soils of Nigeria in Engineering Practice, pp. 61-84.

Oyawoye MO 1972. The Basement Complex of Nigeria. In: dessaugie TFJ, Whiteman AJ (eds) African geology. Ibadan University Press, pp. 66-102.

Oyediran IA & Kalejaiye M 2011. Effect of increasing cement content on strength and compaction parameters of some lateritic soils from Southwestern, Nigeria. *EDGE*, 16: 1507-1514.

Sabat AK 2012. A study on some geotechnical properties of lime stabilised expansive soil –Quarry dust mixes. *Int. J. Emerging Trends in Engr. and Devt*., 1(2): 42-49.

Simon AB, Giesecke J & Bildo G 1973. Use of lateritic soils for Road Construction in North Dahomey. *Engineering Geology*, 7: 197 – 218.

Simon AB, Giesecke J & Bildo G 1973. Use of lateritic soils for road construction in North Dahomey. *Engineering Geology*, 7: 197 – 218.

Soosan TG, Jose BT & Abraham BM 2001. Use of Quarry Dust in Embankment and Highway Construction. *Proceedings of Indian.Geo-Technical Conference*, Indore.

Soosan TG, Sridharan A, Jose BT & Abraham BM 2005. Utilization of quarry dust toimprove the geotechnical properties of soils in highway construction. *Geotech. Testing J.*, 28(4): 1-10.