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PRELIMINARY ANALYSIS OF QUARRY DUST AND BLACK CLAY MIXTURES COMPACTED AT BS LIGHT EFFORT AS AN ESSENTIAL MATERIAL FOR THE CONSTRUCTION OF WATER RESOURCES STRUCTURES

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ABSTRACT
Construction works in civil and water resources engineering are built on soil or rock and in many instances, these formed the raw materials for construction. It is therefore indispensable to understand the physical, mechanical and chemical properties of such orthodox material. Vertisol, also known as Black cotton soils (B.C) is heavy black clay associated with calcium rich parent rock, which have high swelling and shrinkage properties. So also, quarry by-products (Quarry Dust - Q.D) are disposed of as waste from an asphalt plant. Permeability is an important factor in the design of liners whether for canals, dams or landfills. Hence this research seeks to assess the beneficial use of the quarry dust and black cotton soil mixtures for this purpose. The work was carried out on soils from five locations in Biu Local Government Area of Borno State - Nigeria to assess the permeability properties of black cotton soil mixed with quarry dust in order to improve strength, reduce shrinkage and swelling characteristics, particularly when used as liners for water resources structures such as dam embankments. The result of the analysis indicates that, the chemical composition test on the soil mixtures has low salinity and plasticity levels, and slightly acidic. From classification, the soil has a liquid limit of about 50 % and the permeability of the mixture at all the five points was high at 100 % B.C – 0 % Q.D then decreases at 80 % B.C – 20 % Q.D, and at 60 % B.C – 40 % Q.D and went high at 50 % B.C - 50 % Q.D. Therefore, the research recommends that 80 % - 20 % and 60 % - 40 % of B.C - Q.D mixtures can be used as liners, having exhibited a reduced permeability value.

KEYWORDS: *Black cotton soils, BS light compaction, liners, permeability, quarry dust*

1.0 INTRODUCTION
Civil engineering construction works are built on soil or rock and in many cases; these also form the raw materials for construction. The term soil refers to all the un-indurated mineral materials lying above or between strata of bedrock near the earth's surface, including the air, water, organic matter, and other substances, which may be dispersed through the mineral particles (Verruijt, 2012). Soil is a non-

homogenous, porous, earthen material whose engineering properties and behavior are greatly influenced by changes in moisture content and density or compactness (Kadafur, 1996; Mohammed, 2014; Xiaoyang *et al.,* 2019). The design and construction of engineering structures often involve consideration of the soil at depths and in conditions that are far removed from those which are conducive to the growth of vegetation.

The Engineer is interested primarily in the determination and improvement of the strength characteristics of the soil. The properties which are associated with high strength are high density, high internal friction and cohesion, and low moisture content (Krishna, 2002; McCarthy, 2007; Verruijt, 2012). The Engineer treats the soil as another of the many engineering materials with which he deals. In the same way that he must understand and be able to determine the physical, mechanical and chemical properties of such orthodox materials and the characters of its response to the forces to which it is subjected in engineering structures and processes (Verruijt, 2012; Baig *et al.,* 2017).

Vertisol is heavy black clay associated with calcium rich parent rock and found in the relatively dry savannah climate. They are also known as black cotton soils (Keller, 2011). They characteristically have a black upper horizon of about 20 cm and the organic matter content of the soil is low; they usually have free calcium carbonate concentration in the soil profile (Xiaoyang *et al.,* 2019). Vertisols have a heavy texture and dominant montmorillonitic clay fraction and do not normally form under high rainfall and forest vegetation because calcium would be leached out of the profile and the clay mineral would be converted, at least in part, to kaolinite giving a rather different soil over the same parent rock (Oza and Gundaliya, 2012). Black cotton soils have fine particle sizes and consequently low permeability (Baig *et al.,* 2017).

Hydraulic conductivity, symbolically represented as K, is a property of vascular plants, soil, or rock that describes the ease with which water can move through pore space or fractures. It depends on the intrinsic permeability of the material and the degree of saturation. Saturated hydraulic conductivity, Ksat, describes water movement through saturated media (Das, 2010; Verruijt, 2012; Mohammed, 2014).

Permeability is a major factor in determining the use to which soil can be put. Water erosion, reclamation of soils, seepage, settlement, stability of roads and building foundations, crop production, and growth of trees, shrubs, and grasses are all affected to some extent by the ease or difficulty with which soil drains. Yet permeability has not been studied as extensively as the other major soil Engineering properties like strength and compressibility (Das, 2010, Vertoijt, 2012). Black cotton soils occur in India and Africa, they occur as carbonate rocks or rocks rich in ferrumagnesium minerals in previous and present day depression. They have been recorded in Biu, Gombe, Numan, Maiduguri-Gamboru Road, Bauchi and Adamawa respectively in Nigeria. Several estuarine occurrences have also been recorded in the Chad Basin of Borno State (Ola, 1983).

This research work was conducted to find out how the permeability of black clays can be affected by mixing it with quarry dust to improve strength, reduce shrinkage and swelling characteristics, especially when used in liners for dams and landfills. This is achieved by evaluating the chemical composition and physico-chemical properties of quarry dust and black cotton soils (particularly for samples obtained at 0.5 m depth). This also includes evaluating index properties, its compaction characteristics, hydraulic conductivity (or permeability) and the behaviour of quarry dust-black clay mixtures compacted at BS light efforts.

2.0 MATERIALS AND METHODS

The material for this tests are the soil samples (Black cotton) obtained from Biu and quarry dust obtained in Maiduguri (brought from a quarry in Fulka-Goza) in accordance with the British Standard (BS) 1377 specifications and the quarry dust from Marini Asphalt Plant in Maiduguri. Soil chemical composition, pH, electrical conductivity, loss in ignition, carbonates, total organic material, major oxides, SiO2, Al2O3, Fe2O3:, TiO2, CaO, K2O, MgO, Na2O, Vanadium, Chromates and Zinc including geotechnical properties test; mechanical properties - specific gravity, particle size distribution (Hydrometer analysis). Atterberg limits, free swell, BS light compaction, BS heavy compaction, and permeability (hydraulic conductivity tests). The depths of samples collected are 0.5, 1.0 and 1.5 m respectively, to take care of variations in soil samples.

2.1 Materials

2.1.1 Black Cotton Soil and Quarry Dust

Black cotton soil samples collected at five locations each from Biu ie. Mbulachivi (MBC) BP (0.5, 1.0, 1.5m), Mbulachiv BP2 (0.5, 1.0, 1.5m), Mbulachivi BP3 (0.5, 1.0, 1.5m), Kigir (KGR) BP (0.5, 1.0, 1.5m) and Kigir BP2 (0.5, 1.0 and 1.5m) respectively were used for those tests (Eberemu and Sada, 2013; Muhammad and Abdulfatah, 2020). The quarry dust was obtained from Marine Asphalt Plant in Maiduguri which was mixed with the black cotton soil obtained from a rock outcrops and compacted before running the permeability tests at BS light compactive effort (Eberemu and Sada, 2013).

2.2. Chemical Analysis

pH and Electrical Conductivity were obtained following the methods adopted by Toledo (2007) and Hubert and Wolkersdorfer (2015). Titration i.e. total organic content was carried out following the method of Pal *et al.* (2009). Loss on Ignition was evaluated after Hoogsteen *et al.* (2018).

2.3 Determination of Moisture Content and Particle Size Distribution

The moisture contents of the samples were determined following the method of O'Kelly (2014). Mechanical Analysis of the air dried soil is done by separating into various sized fractions by shaking the material through a nest of sieves of varying sizes of mesh and weighing the materials retained on each sieve following the method described by Liu (2009). The hydrometer analysis of the soil was conducted after Kaur and Fanourakis (2016).

2.4 Atterberg Limits Tests

2.4.1 Determination of Liquid Limit Plastic Limit

This test is carried out using the Casagrande apparatus. The soil sample was then placed on a glass plate and thoroughly mixed with water using a spatula. The intimately mixed soil and a water sample is placed in the cup and a groove is made on the soil sample with a grooving tool and the number of blows counted which are regained to cause the sample to flow together and close the groove over a distance of 12.7 mm. The procedure is repeated after remixing the sample until a consistent value is obtained for the number of blows required (Rehman *et al.,* 2020). The plastic limit is determined by rolling out a thread from a portion of the moist soil on a glass plate. Three replicate determinations are made of the minimum moisture content at which the soil may be rolled into a thread of 3 mm in diameter without breaking. The average value of moisture contents is the plastic limit of the soil (Prakash *et al.*, 2009).

2.4.2 Determination of Linear Shrinkage and Free Swells

Linear Shrinkage was measured by taking a portion of the sample used for the liquid limit test and used to fill the linear shrinkage mould and subjected to some strokes of the spatula with the top of the mould levelled as described in Oke *et al.* (2020). Free Swells was determined following the method described by Wilke (2005).

2.5 Determination of Specific Gravity and Hydraulic Conductivity (Falling Head and Constant Head) Tests

The specific gravity of the soil was done after Pawar and Shah (2009). The hydraulic conductivity (falling head) test was conducted by the method described by Nam *et al.* (2021), and the constant head was also performed following the method of Elhakim (2016).

2.6 Compaction Test

Two compaction methods were employed in this work, the standard proctor (BS light) and the modified proctor (BS heavy) after Zvonarić *et al.* (2021).

3.0 RESULTS AND DISCUSSION

The various tests as outlined in the previous chapter were carried out on the soil samples obtained from Biu at five different locations. Results of the chemistry index properties and permeability of quarry dust-black clay mixtures compacted at BS light efforts are tabulated and discussed below.

3.1 Chemical Composition of Black Clay and Quarry Dust

Table 1: Chemical composition of Black Clay

Location	Al_2O_3	SiO_2	K_2O	C_3O	Fe_2O_3	TOC (%)	MgO	Na_2O	ZnO	SO_4	CO_3	LOI (%)	S-S
KGR 1	24.999	40.027	0.289	0.405	1.693	13.26	0.12	3.47	0.003	1.46	3.42	3.46	1.50
KGR 2	24.592	39.271	0.208	0.153	0.992	13.00	0.15	4.15	0.003	1.79	3.42	3.48	1.53
MBC 1	24.661	39.380	0.191	0.402	1.416	9.43	0.13	3.85	0.002	1.95	4.61	3.55	1.51
MBC 2	24.876	39.932	0.299	0.418	1.412	5.80	0.33	2.90	0.001	2.45	2.00	3.67	1.52
MBC 3	24.817	40.748	0.306	0.421	1.199	6.42	0.14	2.63	0.001	2.53	2.50	3.46	1.57

KGR1 – Kigir burrow Pit 1, MBC1 – Mbulachivi burrow Pit 1, S-S - Sesquioxides

Table 2: Chemical Composition of Quarry Dust

Sample I	Al_2O_3	SiO_2	K_2O	C_3O	Fe_2O_3	TOC	Ca	Na	Zn	PO_4	K	LOI %	S-S
QD	6.506	7.200	3.841	0.823	0.974	1.416	0.162	0.133	0.0002	0.0568	0.360	1.900	2.081

QD = Quarry Dust, S-S - Sesquioxides - SiO2/Al2O3 + Fe2O3

The intensity of soil acidity or alkalinity is expressed as pH. In the case of Black clays occurring in the Biu area, Table 3 shows that the pH of the soils varies from 5.43 to 5.97 indicating slightly acidic to mildly alkaline soils. Factors which contributed to these are the high content of bases, especially calcium and magnesium in the profile. The measure of electrical conductivity is related to the salinity of soil and values obtained ranged from 512 to 638 Ms/cm

Table 3: The pH of the soils

Location	Ph
KGR 1	5.50
KGR 2	5.43
KGR 3	5.58
MBC 1	5.62
MBC 2	5.75
MBC 3	5.97

KGR1 – Kigir burrow Pit 1,
MBC1 – Mbulachivi burrow Pit 1

From Table 4, it is evidently proved that the soils have high free swell properties with free swell percent ranging from 49 to 61%, Soils with high free swell are likely to show to high expansive properties; this makes structures constructed upon them to develop cracks. The specific gravity for the black cotton soils as observed for all locations is within the range of 2.48 to 2.55 in Table 4. These results are close to the value of 2.56 as reported by Ola (1983). For purposes of classification in terms of swelling potential, the quarry dust and black cotton soils mixtures used in this study may be qualitatively classified as medium swelling soils (free swell ≤ 50) based on the classification chart for expansive soils in the literature (Holtz, 1959; NBRRI, 1983). Except for soils from the burrow pit KGR 21, MBC 21 and MBC 23, this showed values far greater than 50.

Table 4: Physico-chemical properties

Locations	Depths (m)	Free Swell (FS)	Specific Gravity (SG)
KGR 11	0.5	51	2.50
KGR 12	1.0	50	2.53
KGR 13	1.5	53	2.50
KGR 21	0.5	58	2.49
KGR 22	1.0	55	2.52
KGR 23	1.5	52	2.48
MBC 11	0.5	52	2.43
MBC 12	1.0	50	2.52
MBC 13	1.5	53	2.48
MBC 21	0.5	61	2.51
MBC 22	1.0	54	2.53
MBC 23	1.5	60	2.52
MBC 31	0.5	52	2.47
MBC 32	1.0	50	2.55
MBC 33	1.5	49	2.54

KGR11 – Kigir burrow Pit1, depth 1, **KGR12** - Kigir burrow Pit1, depth 2, **KGR13** – Kigir burrow Pit1, depth 3, **MBC11** - Mbulachivi burrow Pit1, depth 1, **MBC12** - Mbulachivi burrow Pit1, depth 2, **MBC13** - Mbulachivi burrow Pit1, depth 3. **SG** - Specific Gravity, **ES** - Free swell

Table 5 shows that all the samples contain significant amounts of clay-sized and sand-sized particles. Where clay ranges from 38.80 to 56.30 %, sand ranges from 14.60 to 34.60 %, and silt ranges from 16.60 to 38.80 %.

3.2 Particle Size Analysis

Table 5: Hydrometer analysis for Black clay

Locations	Depths (m)	Sand %	Silt %	Clay %
KGR 11	0.5	29.60	24.10	46.30
KGR 12	1.0	24.60	29.10	46.30
KGR 13	1.5	34.60	26.60	38.80
KGR 21	0.5	27.10	16.60	56.30
KGR 22	1.0	14.90	38.80	46.30
KGR 23	1.5	24.60	26.60	48.80
MBC 11	0.5	22.10	34.10	43.80
MBC 12	1.0	17.10	36.60	46.30
MBC 13	1.5	14.90	31.30	53.80
MBC 21	0.5	14.60	29.10	56.30
MBC 22	1.0	14.60	29.10	56.30
MBC 23	1.5	14.90	31.30	53.80
MBC 31	0.5	17.10	26.60	56.30
MBC 32	1.0	29.60	24.10	46.30
MBC 33	1.5	34.60	24.10	41.30

KGR11 – Kigir burrow Pit1, depth 1**, KGR12** - Kigir burrow Pit1, depth 2**, KGR13** – Kigir burrow Pit1, depth 3, **MBC11** - Mbulachivi burrow Pit1, depth 1, **MBC12 -** Mbulachivi burrow Pit1, depth 2, **MBC13 -** Mbulachivi burrow Pit1, depth 3

Table 6 shows the parameters derived from the grading characteristics of Quarry Dust. The various parameters include D10 (effective size), the particle size corresponding to 10 % finer by dry weight, D30, the particle size corresponding to 30 % finer by dry unit weight, D50,(mean size), the particle size corresponding to 50 % finer by dry unit weight and D60, the particle size corresponding to 60 % finer by dry unit weight. The table also shows that the coefficient of uniformity (Cu) and the coefficient of curvature (Cc) which has values of 1.55 and 2.18, respectively. The quarry dust derived-parameter was plotted as shown in Figure 1.

Table 6: Sieve analysis for quarry dust-derived parameters

Sample I	D_{10}	D_{30}	D_{50}	D_{60}	C_u	C_c
Q D	0.17	0.37	0.90	1.40	1.55	2.18

Q D - Quarry Dus

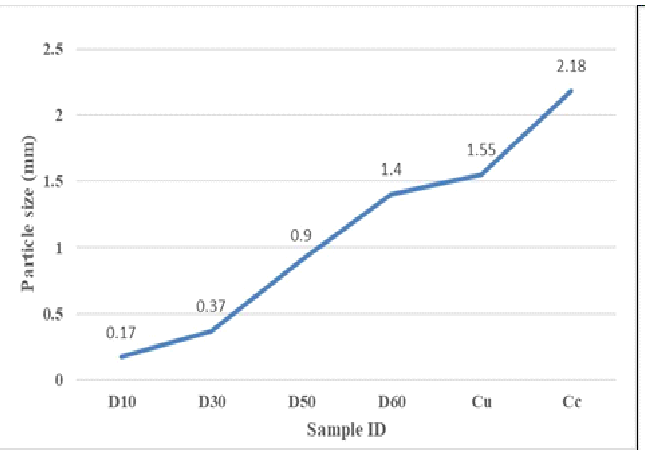

Figure 1: Sieve analysis for quarry dust derived parameter

Table 7 showed that Black clays are characterized by high liquid limit which ranges from 41 to 53 %, plastic limit ranges from 17.7 to 21.9 %, Plasticity index ranges from 21.4 to 33.6 % and linear shrinkage ranges from 13.8 to 17.9 %. Gromko (1994) gave values of linear shrinkage, liquid limit and plasticity index greater 8 %, 30 % and 12 % respectively as among the first criteria proposed for recognition of an expansive soil.

3.3 Plasticity Characteristics

Table 7: Plasticity characteristics

Location	Depths (m)	LL %	PL %	PI %	LS %
KGR 11	0.5	45	19.9	25.1	17.9
KGR 12	1.0	47	19.7	27.3	15.7
KGR 13	1.5	48	18.3	29.7	16.4
KGR 21	0.5	42	17.7	24.3	14.3
KGR 22	1.0	43	20.0	23.0	14.9
KGR 23	1.5	46	20.9	25.1	14.2
MBC 11	0.5	51	18.2	32.8	14.7
MBC 12	1.0	52	21.7	30.3	13.8
MBC 13	1.5	53	19.4	33.6	15.7
MBC 21	0.5	47	20.0	27.0	14.8
MBC 22	1.0	48	21.9	26.1	14.3
MBC 23	1.5	48	18.2	29.8	15.0
MBC 31	0.5	42	20.6	21.4	15.0
MBC 32	1.0	44	20.0	24.0	14.0
MBC 33	1.5	48	20.2	27.8	14.1

KGR11 – Kigir burrow Pit1, depth 1, **KGR12** - Kigir burrow Pit1, depth 2, **KGR13** – Kigir burrow Pit1, depth 3, **MBC11** - Mbulachivi burrow Pit1, depth 1, **MBC12** - Mbulachivi burrow Pit1, depth 2, **MBC13** - Mbulachivi burrow Pit1, depth 3, LL= Liquid Limit, **P L** = Plastic Limit, **P I** = Plastic Index and **L S** = Linear Shrinkage

Two compaction energies were carried out namely B.S light compaction and B.S heavy compaction. For all the soil samples, from Table 8 the optimum moisture content (OMC) ranges between 14.30 to 18.03 % and 13.73 to 15.83 % respectively for all the two compaction efforts employed. Similarly the maximum dry density range from 1.63 to 1.74 Mg/m3 and 1.71 to 1.86 Mg/m3 respectively, for all two compactive efforts. This corresponds to the maximum dry unit weight ranging from 15.90 to 17.07 kN/m3 and 16.78 to 18.25 kN/m3. All the samples showed that with the BS light compaction, low values of maximum dry density with resulting high optimum moisture content were obtained. With the B.S heavy compaction on the other hand, high maximum dry densities with low optimum moisture contents were obtained. The moisture content-dry density relationships are shown in Figures 2 and 3 and Tables 9 and 10 respectively.

3.4 Compaction Characteristics of BS light and BS heavy

Table 8: Compaction characteristics of BS light and BS heavy

Location	OMC (%)	B.S Light MDD (Mg/m^3)	MDUW (kN/m^3)	OMC (%)	B.S Heavy MDD (Mg/m^3)	MDUW (kN/m^3)
KGR 11	14.30	1.70	16.68	14.10	1.82	17.85
KGR 12	14.43	1.67	16.38	14.78	1.86	18.25
KGR 13	15.30	1.63	15.99	15.42	1.80	17.66
KGR 21	15.30	1.67	16.38	14.02	1.86	18.25
KGR 22	16.53	1.65	16.19	14.48	1.84	18.05
KGR 23	15.32	1.64	16.09	15.83	1.80	17.66
MBC 11	14.68	1.66	16.28	13.73	1.84	18.05
MBC 12	18.52	1.65	16.19	14.82	1.73	16.97
MBC 13	18.03	1.68	16.48	15.82	1.84	18.05
MBC 21	14.38	1.74	17.07	14.72	1.80	17.66
MBC 22	17.40	1.63	15.99	14.52	1.72	16.87
MBC 23	15.32	1.65	16.19	14.72	1.82	17.85
MBC 31	17.68	1.65	16.19	13.82	1.76	17.27
MBC 32	17.40	1.71	16.78	13.98	1.76	17.27
MBC 33	15.62	1.62	15.90	14.84	1.71	16.78

KGR11 – Kigir burrow Pit1, depth 1, **KGR12** - Kigir burrow Pit1, depth 2, **KGR13** – Kigir burrow Pit1, depth 3, **MBC11** - Mbulachivi burrow Pit1, depth 1, **MBC12** - Mbulachivi burrow Pit1, depth 2, **MBC13** - Mbulachivi burrow Pit1, depth 3**, OMC** = Optimum moisture content, **MDD** = Maximum dry density, **MDUW** = Maximum dry unit weight, **B.S LIGHT** = British standard light compaction and **B.S HEAVY** = British standard heavy compaction

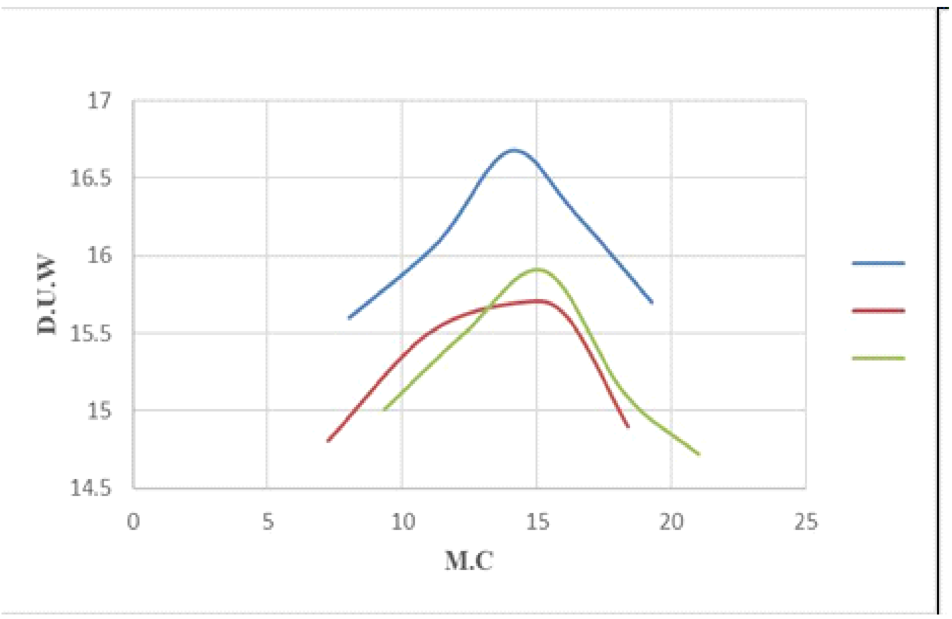

Figure 2: Dry unit weight versus moisture content for the soil sample (KGR BP 1)

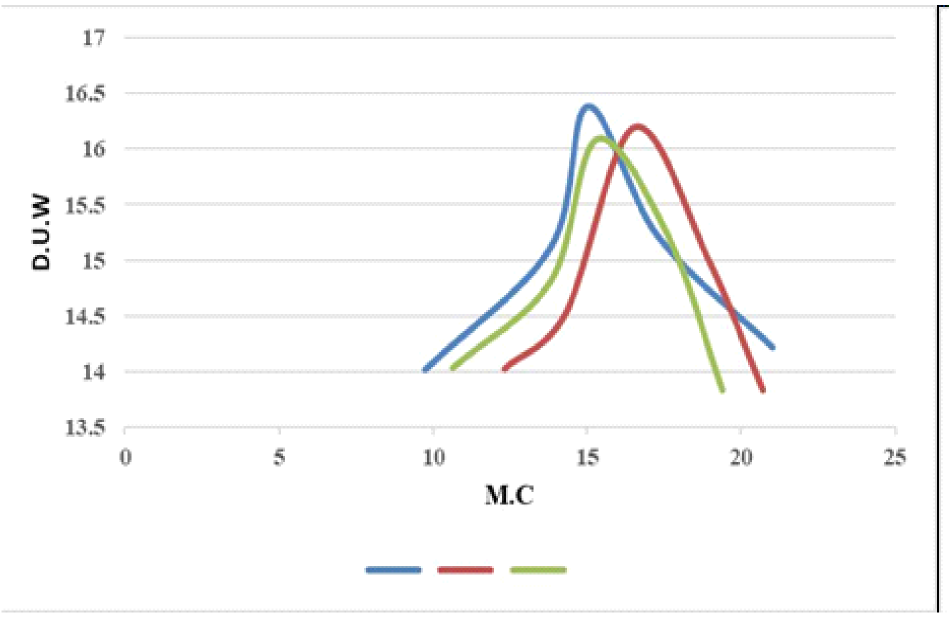

Figure 3: Dry unit weight versus moisture content for the soil sample (KGR BP 2)

Table 9: Moisture content-dry unit weight for the soil samples KGR Bp1

MC	DUW	MC	DUW	MC	DUW
	0.5 BSL		1.0 BSL		1.5 BSL
8.07	15.60	7.26	14.81	9.36	15.01
11.36	16.09	10.98	15.50	12.32	15.50
14.03	16.68	14.43	15.70	15.30	15.90
16.4	16.28	16.16	15.60	18.26	15.11
19.26	15.70	18.39	14.90	21.00	14.72

MC - moisture content, **DUW-** Dry unit weight, **BSL -** British Standard light

Table 10: Moisture content-dry unit weight for the soil samples KGR Bp2

MC	DUW 0.5 BSL	MC	DUW 1.0 BSL	MC	DUW 1.5 BSL
9.73	14.02	12.32	14.02	10.63	14.03
13.80	15.11	14.30	14.52	13.81	14.81
15.03	16.38	16.53	16.19	15.32	16.09
17.31	15.21	18.91	15.01	17.63	15.21
21.03	14.22	20.68	13.83	19.38	13.83

MC - Moisture content**, DUW -** Dry unit weight**, BSL** – British Standard light

The result of permeability tests on sample compacted at the B.S light energy are shown in Table 11, expressed in cm/s, and are for the following mix ratios of black clay-quarry dust mixtures i.e. 100 – 0 %, 80 – 20 %, 60 – 40 % and 50 – 50 %.

3.5 Permeability of Quarry Dust-Black Clay Mixtures

Table 11: Permeability of Quarry Dust-Black Clay mixture compacted at B.S Light effort

Location	Water added	4%	8%	12%	16%	20%
KGR BP 1	100 - 0%	2.4915×10^{-5}	5.5754×10^{-6}	4.4158×10^{-6}	9.0570×10^{-6}	9.7722×10^{-6}
	80 - 20%	1.5472×10^{-5}	2.4476×10^{-5}	8.2930×10^{-6}	3.0557×10^{-6}	1.6060×10^{-6}
	60 - 40%	1.0946×10^{-5}	1.6750×10^{-5}	7.7796×10^{-6}	1.1934×10^{-5}	9.8027×10^{-6}
	50 - 50%	1.0945×10^{-5}	5.3222×10^{-6}	2.2076×10^{-6}	9.7636×10^{-6}	6.1737×10^{-6}
KGR BP 2	100 - 0%	1.2388×10^{-5}	6.2708×10^{-6}	3.9792×10^{-6}	9.5556×10^{-6}	1.0394×10^{-5}
	80 - 20%	1.6075×10^{-5}	2.4508×10^{-5}	9.0906×10^{-6}	4.5944×10^{-6}	2.7520×10^{-6}
	60 - 40%	1.1145×10^{-5}	1.3619×10^{-5}	8.0307×10^{-6}	1.2652×10^{-5}	9.5416×10^{-6}
	50 - 50%	1.1213×10^{-5}	5.6300×10^{-6}	2.2023×10^{-5}	9.5672×10^{-6}	7.1219×10^{-6}
MBC BP 1	100 - 0%	1.1196×10^{-5}	5.9706×10^{-6}	2.7890×10^{-6}	9.6550×10^{-6}	9.7505×10^{-6}
	80 - 20%	1.4904×10^{-5}	2.3902×10^{-5}	7.3345×10^{-6}	1.8961×10^{-6}	1.5078×10^{-6}
	60 - 40%	1.0867×10^{-5}	1.5905×10^{-5}	7.2011×10^{-6}	1.1125×10^{-5}	9.1957×10^{-6}
	50 - 50%	1.2412×10^{-5}	5.1669×10^{-6}	2.2185×10^{-5}	8.6742×10^{-6}	5.7895×10^{-6}
MBC BP 2	100 - 0%	1.1022×10^{-5}	5.5880×10^{-6}	3.2237×10^{-6}	9.1700×10^{-6}	9.9524×10^{-6}
	80 - 20%	1.4925×10^{-5}	2.3898×10^{-5}	6.5411×10^{-6}	2.1255×10^{-6}	1.6651×10^{-6}
	60 - 40%	1.0812×10^{-5}	1.5247×10^{-5}	6.9408×10^{-6}	1.0560×10^{-5}	8.0346×10^{-6}
	50 - 50%	1.1129×10^{-5}	4.8341×10^{-6}	2.1427×10^{-5}	7.7534×10^{-6}	4.0402×10^{-6}
MBC BP 3	100 - 0%	1.1522×10^{-5}	5.6670×10^{-6}	3.8904×10^{-6}	4.3884×10^{-5}	7.4063×10^{-6}
	80 - 20%	1.5077×10^{-5}	2.4133×10^{-5}	6.9557×10^{-6}	2.1039×10^{-6}	1.7792×10^{-6}
	60 - 40%	1.0777×10^{-5}	1.5420×10^{-5}	7.2505×10^{-6}	1.1033×10^{-5}	8.6937×10^{-6}
	50 - 50%	1.1001×10^{-5}	5.0049×10^{-6}	2.2134×10^{-5}	8.2021×10^{-6}	4.2097×10^{-6}

100 BC– 0 QD (%)
80 BC – 20 QD (%)
60 BC – 40 QD (%)
50 BC – 50 QD (%)

BC- Black Clay, **QD** - Quarry Dust, **KGR BP 1** – Kigir burrow Pit 1, **MBC BP 1 -** Mbulachivi burrow Pit 1

The permeability of the mixture at all the five points is high at 100 % B.C – 0 % Q.D and decreases at 80 % B.C – 20 % Q. D. it also decreased at 60 % B.C – 40 % Q.D and went high at 50 % B.C – 50 % Q.D. The plots of permeability versus moulding water content for soils at BS Light compaction (KGR BP1) and permeability versus moulding water content for soils at BS Light compaction (KGR BP2) is shown in Figures 4 and 5, respectively.

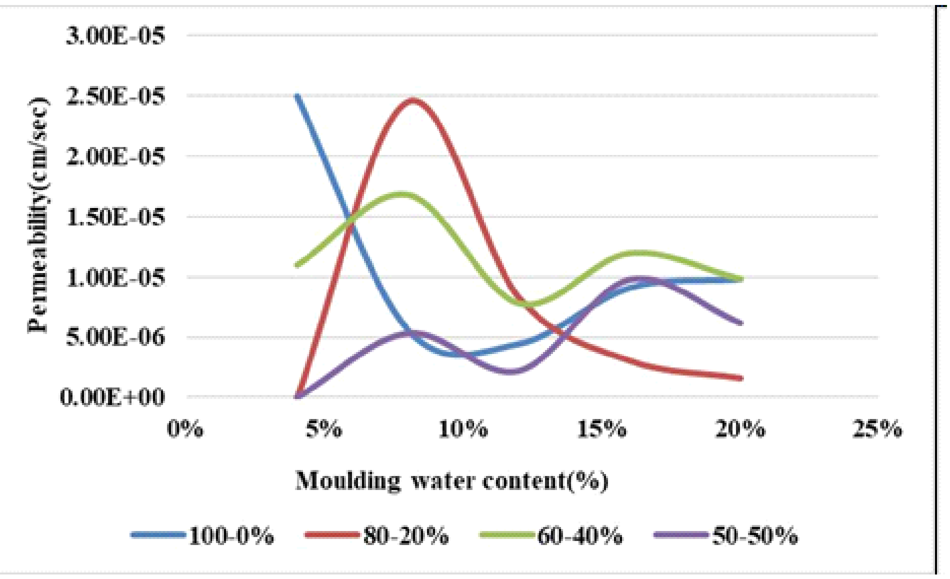

Figure 4: Permeability versus Moulding water content for soils at BS Light Compaction (KGR Bp1)

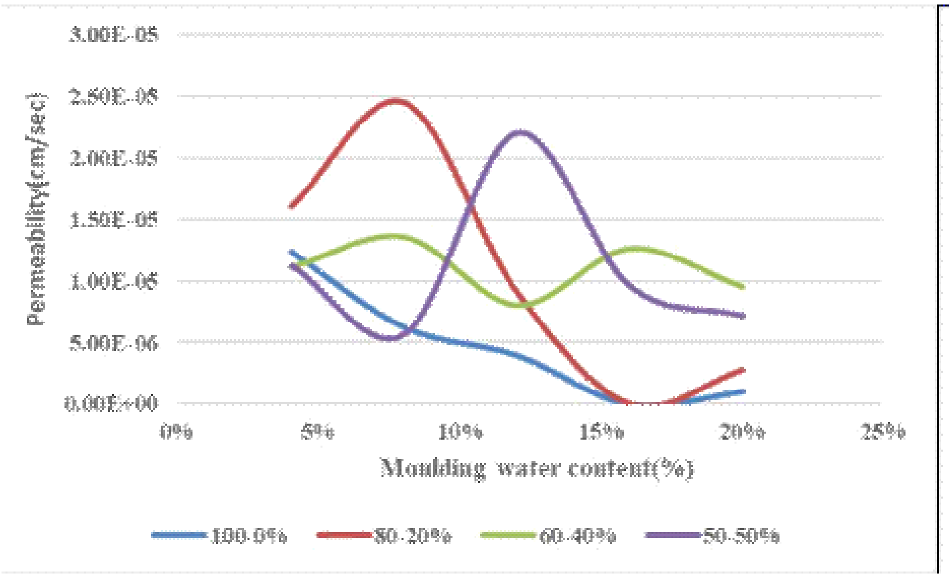

Figure 5: Permeability versus moulding water content for soils at BS Light Compaction (KGR Bp2)

4.0 CONCLUSION AND RECOMMENDATIONS CONCLUSION

From the results of various tests conducted as well as the hydraulic conductivity studies, as presented. It can be concluded that the chemical composition test shows that the soils have low salinity levels and are slightly acidic. The soils are of low plasticity and have a liquid limit of about 50 % from the classification. The permeability of the mixture at all the five points was high at 100 % B.C – 0 % Q.D and decreases at 80 % B.C – 20 % Q. D., and also decreased at 60 % B.C – 40 % Q.D and showed some levels of equality at 50 % B.C – 50 % Q.D.

RECOMMENDATIONS

Chemical, physical and geotechnical properties of the black clay soils and quarry dust have been studied; including the hydraulic conductivity of the quarry dust-black clay mixtures. In view of the experimental analysis, the following recommendations were made;

(i) 80 % - 20 % and 60 % - 40 % of B.C - Q.D, mixtures can be used as liners having shown reduced permeability values.

(ii) Studies can also be carried out to see the effects of using a re-used sample of the mixtures

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