STABILIZATION OF BLACK COTTON SOILS FROM NORTH-EASTERN NIGERIA WITH SODIUM SILICATE

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Abstract

This work involves stabilization of black cotton soils from North-Eastern Nigeria with sodium silicate. Black cotton soil samples were collected from three locations within the studied area and their natural geotechnical properties determined in the laboratory. Sodium silicate was mixed with the soils in varied percentages of 2,4,6,8, and 10% and their responses monitored by testing in the laboratory. The test carried out on both the natural and treated samples are classification which includes Atterberg limits, particle size distribution; and strength characteristics through compaction and California Bearing ratio determination. The three soil materials tested were classified as A-7-6 with natural California Bearing Ratio (CBR) values ranging from 28.7% to 32.5%, giving weak subgrade to fair subbase materials. On stabilization, the plasticity indices of the soils were reduced considerably with remarkable improvement on the compaction characteristics. The CBR values increased to between 88% to 95%, and with percentage increase in strength of the stabilized soil samples over the natural soils up to 214%. The unsuitable materials were thus improved to suitable base materials.

Keywords: Stabilization, Laterite, Black Cotton Soils, Sodium Silicate, California Bearing Ratio

INTRODUCTION

Road construction in most developing countries involves the use of soil materials for the subbase and base of the roads. Some of these soil materials when encountered on site may not be directly suitable for use due to their poor strength characteristics, and when such occurs, the engineer is left with the choice of borrowing suitable materials from other sites or improves on the strength of the available ones (Oluyemi and Owolabi, 2003). When materials are imported to the site, the cost of construction becomes high due to delay in construction, increased haulage cost and time wastage, so the engineer with the choice of adding stabilizing agents to improve the properties of the available soil on site using various means of soil improvement techniques (Megan *et al.*, 1999, Allan *et al.*, 2003).

Black cotton soils are tropical expansive clay deposits which are particularly troublesome due to their high swelling and shrinkage potentials. They occur principally in semi arid tropics with marked alternating wet and dry seasons (Madedor and Lal, 1985, 1991). They are found in Australia, India, South Africa, Ethiopia, Tanzania, Asia and some other Africa countries especially in North Eastern Nigeria. Ola (1977, 1978, 1983, 1987, 1988) in his work described black cotton soils as being highly plastic silty clays formed by the weathering of basalt rock, shale and clay sediments. The soil contained a high proportion of montmorrilonite, with kaolinite and quartz making up the remainder (Ibrahim, 1983). The high shrinkage and swelling of these soils has caused a lot of problems with the use of the soils for engineering construction works due to excessive cracking which results on use especially for road works (Nigerian Building and Road research Institute, 1983).

Cement has been used with great success to stabilize naturally unsuitable soils, but the chemical conditions of some of the soils can inhibit the normal hardening of cement or lead ultimately to loss of durability or high construction cost for the highly plastic clay soils (Local Highway Technical News, 2007). Bituminous stabilization is also used for road surfacing all over the world, but has its own disadvantage in terms of energy loss during heating, it’s dependent on machines to ensure maximum production and quality and negative effect on the environment and human exposed to the hazardous emissions produced in the industry (TRRL, 1986).

In view of these, there has been increasing need for sustainable development of roads all over the world, which has encouraged research into the use of alternative road materials to complement the conventional one. There are some nontraditional chemical stabilizers now in the market which may offer viable alternatives for stabilizing weak soils at reduced construction cost (Eyo, 2006).

It is against this background that this research work is brought up to assess the suitability or otherwise of using sodium silicate to improve the natural geotechnical characteristics of black cotton soils for road construction works.

Naturally occurring silicate minerals make up major portion of the earth’s crust. Studies in the 1920s pointed out that prior to 1828, sodium silicate solutions were thought to be composed of products of hydrolysis, colloidal silicic acid, hydroxide ion, and sodium ion. The silicate solutions also contain crystalloidal silica which was thought to be the components of the known crystalline sodium silicates, charged aggregates of these unit structures and silica, or definite complex silica ions (Encyclopedia of Chemical Technology, 1982). They are produced by charging good quality and pure sand and sodium carbonate (soda ash) in selected proportions into a furnace resembling that used for glass manufacture at a temperature between 1200-1425°C. The material has been used as adhesives and binder applications after the turn of the century. These applications are generally based on the ability of silicates to form gels or react with multivalent metal ions or oxide surfaces in solution. Currently, the primary use of soluble silicate are as sources of silica (40%) for detergency (32%), in paper and board adhesives (6%) and miscellaneous (22%). They can also be used to manufacture synthetic pigments and filers, silica gels and solutions and synthetic clays. Other uses include cement manufacture, bleaching, water treatment, ore beneficiation and soil stabilization.

AIM AND OBJECTIVES OF THE RESEARCH.

The aim of this research is to evaluate the use of sodium silicate to stabilize and improve the geotechnical properties of black cotton soils for road construction and maintenance purposes.

The specific objectives are to:

(i) determine the physical and chemical properties of the chemical stabilizer in the laboratory,

(ii) collect some representative black cotton soil samples from North-Eastern Nigeria and evaluate their natural geotechnical characteristics,

(iii) stabilize the black cotton soils with sodium silicate in varied percentages and monitor performance, and

(iv) evaluate the effectiveness or otherwise of the chemical stabilizer for soil strength improvement.

STATEMENT OF THE PROBLEM

Black cotton soils are tropical expansive clay deposits, which occur principally in semiarid tropics with marked alternating wet and dry seasons (Madedor and Lal, 1985). They are highly plastic silty clays formed by the weathering of basalt rock, shale and clay sediments with a high proportion of expansive montmorrilonite, kaolinite and quartz making up the remainder (Ola, 1983). They appear firm in their dry state, swell up while wet and become highly unstable. They possess clay minerals of the smectite group which typically have a high swell and shrink potential and possess contraction cracks (Ibrahim, 1983).

According to Ola (1978, 1987), they have a black upper (20cm) horizon due to the presence of a black colored humus-clay complex with relatively low organic content and free calcium carbonate concretions with heavy texture. Massive expansion and contraction of the clay minerals takes place leading to the formation of wide and deep cracks, low permeability, high plasticity, expansiveness and shrinkage of the soils when used (Madedor and Lar, 1991). They are vastly available in North Eastern Nigeria lying within the Chad basin and the upper Benue trough (Adesunloye, 1987). Due to the negative characteristics of black cotton soils, they have become problem soils in the areas where they exist and their use has thus been limited.

This work is brought up to evaluate the performance characteristics of black cotton soils when stabilized with sodium silicate for possible improvement on their geotechnical characteristics.

LIMITATION OF THE RESEARCH

The research involved collection of representative samples of black cotton soils from North-Eastern Nigeria, their characterization in the laboratory to assess their natural geotechnical properties, and stabilization with sodium silicate to evaluate the effectiveness of the chemical to improve the soil's strength for construction purposes.

MATERIALS AND METHOD

Representative black cotton soils were collected from different locations in North-Eastern Nigeria and their geotechnical properties determined in the laboratory. The soil samples collected from Numan – Jalingo road, Numan – Yola road, and Numan - Gombe road in North – Eastern Nigeria.

The effectiveness of the stabilizer for soil strength improvement was studied by mixing sodium silicate with the collected soil samples in percentages of 2, 4, 6, 8, and 10, and performance tested in the laboratory. The laboratory tests carried out include determination of the Atterberg limits (liquid limit, plastic limit, and plasticity index), particle size characteristics, compaction characteristics, California Bearing Ratio (CBR) using standard ASTM specifications.

Figure 1shows the study locations.

LABORATORY TEST RESULTS AND DISCUSSIONS

Chemical Characteristics of Sodium Silicate

Soluble silicate glasses are manufactured usually in oil, electric or gas-fired open-hearth regenerative furnaces. The glass is obtained by reaction of quartz sand and sodium carbonate (soda ash) at a temperature sufficient to provide a reasonable quartz dissolution rate in the molten batch and a manageable melt viscosity. The reaction rate of quartz with Na_2CO_3 is controlled by silica diffusion and varies inversely with the square of the radius of the quartz particle). As Na_2CO_3 melts and envelops the sand grains, the slow process of quartz network breakdown and diffusion into the melt occurs.

The melts produced are very corrosive toward refractory materials and care is required in furnace design. Where electric power is available and costs are low, electric melting furnaces can be used satisfactorily. The sand and soda ash required for the manufacture of the soluble silicate must be of high purity. Typically, a no. 1 grade of glass sand containing no more than 300 ppm iron and a medium density soda ash, which is obtained from mined Trona ore is used.

The fused melt is drawn from the furnace continuously in a thin steam and solidified by passing onto a moving chilled conveyor of steel modes where it cools to a semi-transparent solid. The hot melt could be sprayed with a stream of cold water to break them into small fragments which on grinding yields solid granular sodium silicates or it may be passed into a rotary dissolver, where the material is dissolved by superheated steam.

The minerals are slightly soluble and are generally in dynamic chemical equilibrium with the mineral components of the aqua sphere in the process of mineral breakdown and re-formation. Silicate solutions do not contain very large particles; however, aggregation of particles was indicated in high ratio solutions at high solids levels. The material is a colourless and odourless liquid. Laboratory test result shows that the chemical has a pH of 9.5, specific gravity and density of 0.96 and 1.172g/cm^3 respectively and also contain 23% of copolymer. The material used is a diluted solution of sodium silicate, a whitish odourless alkaline salt of a strong base and weak acid. The result of the chemical analysis of the imported and local stabilizers is as shown on Table 1.

Characteristic of Natural and Tested Soil Samples

Table 2 is the summary of the particle size distribution of the black cotton soil samples tested; Table 3 shows the summary results of the Atterberg's limits; while Table 4 shows the compaction and strength characteristics of the with the particle size curves shown in Figure 2.

(i) Black cotton soil from Yola-Gombe Road

The particle sizes are 0.1% gravel, 10.2% sand fractions and 32% of silt and 57.7% clay fractions (Table 2) with LL of 58.4%, PL of 32.5% and PI of 25.9% and LS of 9.8% indicating a soil with high shrinkage characteristics (Table 3). The soil is classified as A-7-6. The MDD and OMC are 18.9kN/m^3 and 15.5% respectively with a CBR value of 28.7% (Table 4). The soil is not recommended for either the subbase or base layers due to the high clay content, which will result in high swelling and eventual failure of the pavement if used.

Treatment with the sodium silicate led to reduction in the plasticity from the natural value to 21% at 2% mix and to 8.8% at 10% mix (Table 5). Also the LS reduced considerably. This is shown on Figure 3. Treating this soil sample with this stabilizer will definitely reduce the swelling and cracking which is generally associated with black cotton soils especially for road works. As shown on Figure 4 and Table 6, the sample had improvement on the MDD from natural value of 18.9kN/m^3 to 20.6kN/m^3 with 4% mix of sodium silicate.

Also in Table 6 and on Figure 5, the CBR also increased from 28.7% natural value to a maximum of 90.1% with sodium silicate at 4% mix. This shows a percentage increase of 214% of using sodium silicate over the strength of the natural soil.

(ii) Black cotton soil from Numan-Jalingo Road

This contains 0.2% gravel, 13.0% of sand fraction 30% of silt and 56.8% clay fractions (Table 2). The Atterberg limits are 53.3% liquid limit, 31.7% plastic limit and 21.6% plasticity index and linear shrinkage of 9.2% (Table 3). The soil is also classified as A-7-6. The strength characteristics gave a CBR of 28.7% (Table 4), which also confirms an unsuitable subbase and base materials with high shrinkage and swelling characteristics.

Addition of sodium silicate reduced the plasticity of the soil at all the mix ratios with increasing stabilizer content with minimum values of 8.8% PI and 3.0% LS at 10% mix (Table 5). This is also shown on Figure 6. Stabilizing this soil sample also improved the compaction and strength characteristics. The MDD increased from 21.4kN/m^3 natural value to 21.8kN/m^3 upon treatment with 4% sodium silicate. In Table 6, the CBR also increased from a natural value of 28.7% to maximum values of 88% with sodium silicate. In Table 7, stabilizing the soil with the sodium silicate gave percentage increase of 207% over the CBR value for the natural soil.

(vi) Black cotton soil from Numan-Yola Road

The particle size analysis of the black cotton soil from this location indicates a silty clay sand with 0.2% gravel fraction, 16.0% sand, 27% silt and 56.8% of clay fractions (Table 2) having PI of 19% and LS of 8.9% (Table 3) The sample is also classified as A-7-6. The MDD and OMC are 18.2 kN/m^3 and 14.9 % respectively while the CBR value is also 32.5% (Table 4). It is a fair subgrade material but naturally unsuitable for the subbase or base layers of roads.

With the addition of sodium silicate to this soil sample, there is also reduction in the plasticity of the soil from 2% to 10% and improvement on the compaction and strength characteristics. With 4% sodium silicate, the plasticity index reduced to 10.1% from the natural value of 19.0% with the linear shrinkage reducing from the natural value of 8.9% to 6.0%. The results are shown in Table 5 and on Figure 6. For the compaction characteristics, there was increase in the MDD at 4% sodium silicate from 18.2kN/m^3 to 21.8kN/m^3. The CBR value also increased from 32.5% natural value to 95% at 4% sodium silicate. Treatment with sodium silicate gave percentage increase of 192% over the natural soil strength.

Conclusions

The black cotton soil from Yola – Gombe and Numan – Jalingo roads contain high proportions of clay and silt fractions. They will be susceptible to swelling and cracking of road pavements. They are classified as A-7-6 and thus unsuitable for road construction without improvement.

Test results have shown that local stabilizer 3, acrylic copolymer is best suited to improve the strength of all tested soils especially the black cotton soils by reducing their plasticity, swelling and shrinkage characteristics. With these stabilizers, some of the unsuitable widely available soil materials could be improved and used for road construction works. This will definitely help in the provision of good road networks in the areas where they exist.

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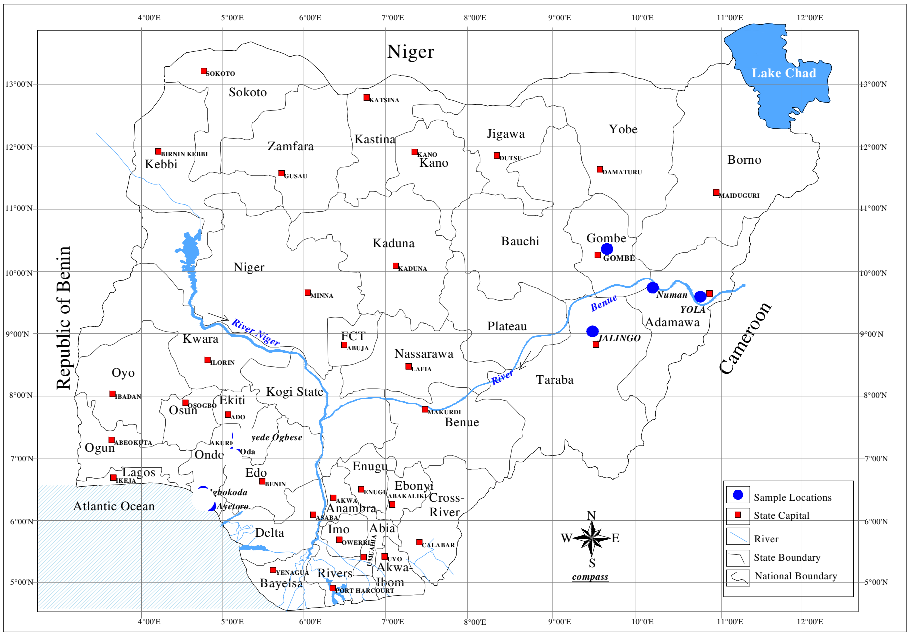


Fig. 1: Map of Nigeria Showing the Soil Sample Locations

Table 1: Summary Result of Physical and Chemical Analysis of Sodium Silicate used

Parameter	**Sodium Silicate**
Physical form	Liquid
Appearance	Colourless
Odour	Odourless
PH	9.5
Specific gravity	0.96
Volatility	-
Density	1.172g/cm^3
SCopolymer	23%
Vinyl acetate (Total solids)	-
Other Ingredients:	Al_2O_3 = 0.14% MgO = 0.02% SiO_2 = 70.3% CaO = 0.52% Na_2O = 29% TiO_2 = 0.02
Water	77%

Table 2: Summary of Particle Size Distribution of Soil samples

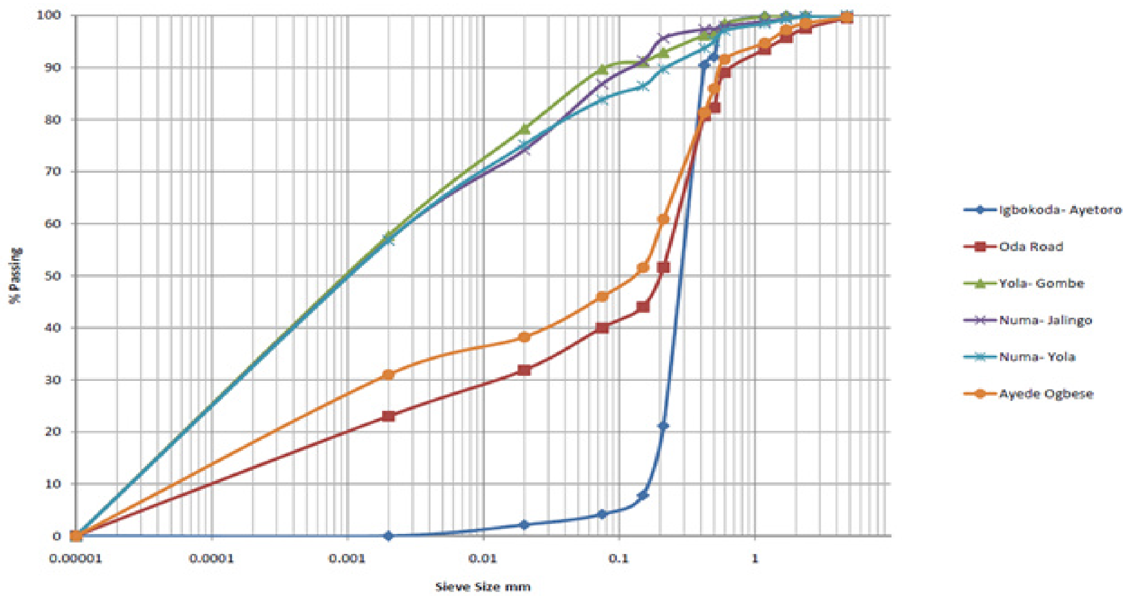
Sample location	Gravel Fractions, %	Sand Fractions, %	Silt fractions, %	Clay Fractions, %
A. Yola – Gombe road	0.07	10.22	32.0	57.74
B. Numan – Jalingo road	0.16	12.98	30.0	56.86
C. Numan – Yola road	0.22	15.98	27.0	56.8

Table 3: Summary Results of the Atterberg's Limits of Natural Soil Samples

Samples/ Location	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Linear Shrinkage, %
A. Yola – Gombe road	38.4	12.5	25.9	9.8
B. Numan-Jalingo Road	33.3	11.7	21.6	9.2
C. Nurman – Yola Road	31.5	12.5	19.0	8.9

Table 4: Summary of Compaction Characteristics and California Bearing Ratio of Natural Soil Samples

Samples/ Location	Optimum Moisture Content, OMC %	Maximum Dry Density, MDD, KN/m^3	California Bearing Ratio, % (unsoaked)
A. Yola – Gombe Road	15.1	18.9	22.5
B. Numan-Jahingo Road	15.5	21.4	28.7
C. Nurman – Yola road	14.9	18.2	32.5



Clay	Silt			Sand			Gravel		
	Fine	Medium	coarse	Fine	Medium	Coarse	fine	medium	coarse

Fig. 2: Particle Distribution Curves of the Collected Soil Samples

TABLE 5: EFFECT OF SODIUM SILICATE ON PLASTICITY OF SOIL SAMPLES

SAMPLE	LL%	MEAN LL%	PL%	MEAN PL%	PI%	MEAN PI%	LS%	MEAN LS%
Yola Gombe, 0%	51.6		37		28.0		10.5	
	60.5	58.4	33	32.5	27.1	25.9	11.1	9.8
	63.1		27.5		22.6		7.8	
2% additive	50.9		31		19.9		5.9	
	46.1	48.5	21	25.8	25.1	21.0	8.5	6.9
	48.5		25.5		23		6.3	
4% additive	41.8		25.1		18.7		6.5	
	39.1	40.8	20.5	22.8	18.6	18.4	5.6	5.8
	41.5		22.8		18		5.3	
6% additive	35.0		22		13		5.1	
	32	35.0	18	19.9	14	15.1	4.6	4.5
	38		19.7		18.3		3.8	
8% additive	33.4		19		14.4		4	
	30	32.1	16.5	17.9	13.5	12.2	3.5	3.7
	32.9		18.2		14.7		3.6	
10% additive	26.1		16.8		9.3		3.5	
	23.5	25.3	16.6	16.5	6.9	8.8	2.7	3.0
	26.3		16.1		10.2		2.8	
Numan-Jalingo, 0%	48.5		35.7		21.4		12.5	

	51.3	53.3	26.2	31.7	22.5	21.6	7.6	9.2
	60.1		33.2		20.9		7.5	
2% additive	52.5		23.2		29.3		9.8	
	35.2	41.5	24.9	25.0	10.3	16.5	4.7	6.5
	36.8		26.9		9.9		5.0	
4% additive	35.2		18.5		16.7		7.1	
	33.8	33.0	20.0	20.5	13.8	12.5	5.3	6.0
	30.0		23.0		7.0		5.6	
6% additive	30.5		13.6		17.0		5.5	
	28.7	29.4	18.3	17.4	10.4	12.0	3.8	4.5
	29.0		20.3		8.7		4.2	
8% additive	26.8		15.3		11.5		4.2	
	24.8	25.5	12.9	13.7	11.9	11.8	3.7	3.8
	24.9		12.9		12.0		3.5	
10% additive	25.9		13.5		12.4		3.2	
	24.2	24.8	11.2	12.7	13.0	12.1	3.0	3.0
	24.3		13.4		10.9		2.8	
Numan-Yola, 0%	52.9		28.8		20.1		9.0	
	48.8	51.5	35.6	32.5	16.6	19.0	9.0	8.9
	52.8		33.1		20.3		8.7	
2% additive	40.2		24.1		16.1		7.5	
	36.1	37.3	25.8	23.8	10.3	13.5	5.6	6.3
	35.6		21.5		14.1		5.8	
4% additive	33.0		18.6		14.4		6.1	
	29.6	30.4	22.8	20.3	6.8	10.1	5.8	6.0
	28.6		19.5		9.1		6.1	
6% additive	29.5		18.9		10.6		5.3	
	28.0	28.1	19.5	19.6	8.5	8.5	5.0	5.1
	26.8		20.4		6.4		5.0	
8% additive	25.1		15.6		9.5		5.3	
	22.3	23.1	16.0	16.1	6.3	7.0	4.1	4.5
	21.9		16.7		5.2		4.1	
10% additive	21.8		13.5		8.3		4.0	
	19.5	20.5	14.0	14.5	5.5	6.0	2.8	3.0
	20.2		16.0		4.2		2.2	

TABLE 6: STRENGTH CHARACTERISTICS OF STABILIZED SOIL SAMPLES WITH SODIUM SILICATE (LOCAL STABILIZER I)

SAMPLE	OMC %	MEAN OMC %	MDD, kN/m^3	MEAN MDD kN/m^3	CBR %	MEAN CBR %
Yola-Gombe, 0%	16.0		19.5		30.9	
	15.6	15.5	19.1	18.9	27.7	28.7
	14.9		18.1		27.5	
2% additive	15.5		19.0		75.6	
	15.0	15.0	19.1	19.2	66.8	70.5
	14.5		19.5		69.1	
4% additive	15.1		22.0		93.0	

	16.1	15.1	20.7	20.6	90.3	90.1
	14.1		19.1		87.0	
6% additive	14.5		18.9		85.1	
	14.0	13.9	18.8	18.6	84.8	82
	13.2		18.1		76.1	
8% additive	14.1		18.1		75.0	
	12.6	13.2	17.1	17.4	70.6	71.2
	12.9		17.0		68.0	
Numan-Jalingo, 0%	16.1		21.8		30.5	
	15.6	15.5	21.6	21.4	30.4	28.7
	14.8		20.8		25.2	
2% additive	15.1		20.5		75	
	14.2	14.5	20.4	19.8	71	72
	14.2		18.5		70	
4% additive	15.2		21.6		93	
	13.6	14.0	21.5	21.8	86	88
	13.2		22.3		85	
6% additive	14.1		18.5		74	
	14.2	13.8	17.7	17.8	84	80
	13.1		17.2		82	
8% additive	12.8		14.5		75	
	13.1	13.1	16.1	15.6	69	69
	13.4		16.2		63	
10% additive	12.7		16.1		65	
	13.0	13.0	14.7	15.2	60	61
	13.3		14.8		58	
Numan-Yola, 0%	15.3		18.0		30.1	
	14.9	14.9	18.1	18.2	32.9	32.5
	14.5		18.5		34.5	
2% additive	15.0		21.1		80.0	
	14.8	14.7	20.6	20.0	81.8	82
	14.3		18.3		84.2	
4% additive	14.3		21.9		98	
	14.3	14.2	20.4	21.8	95	95
	14.0		23.1		92	
6% additive	12.9		19.6		92	
	12.9	13.1	18.5	18.8	89	88
	13.5		18.3		83	
8% additive	13.2		18.1		85	
	13.0	12.9	16.3	17.1	81	82
	12.5		16.9		80	
10% additive	13.1		18.0		77.5	
	11.7	12.0	14.9	16.0	78.7	76.1
	11.2		15.1		72.1	

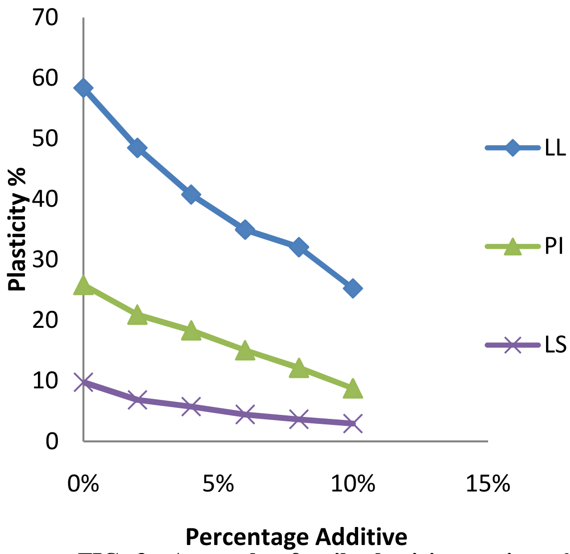


FIG 3: A graph of soil plasticity against % Additive using Sodium silicate for Yola-Gombe soil samples

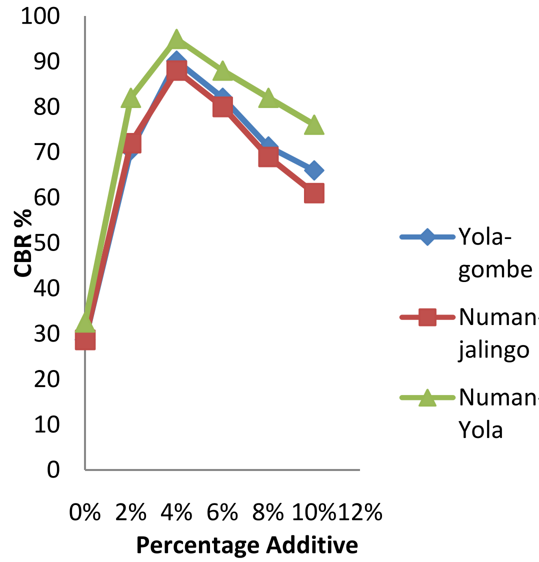


FIG 5: Variation of CBR with Sodium silicate for Yola-Gombe, Numan-Jalingo and Numan-Yola soil samples.

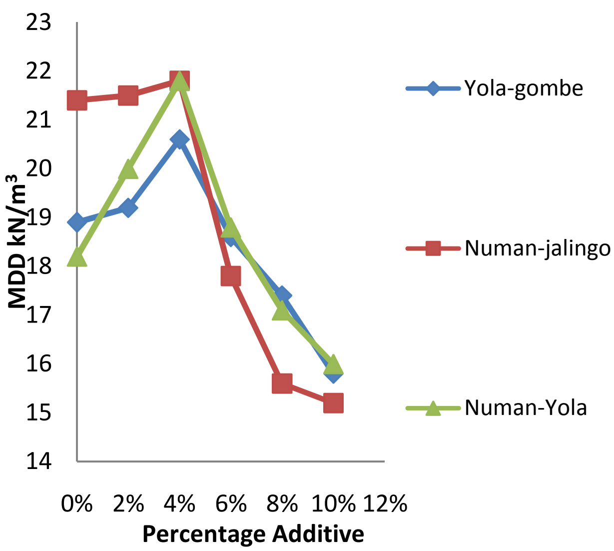


FIG 4: Variation of MDD with % Additive for Yola-Gombe, Numan-Jalingo and Numan-Yola soil samples using Sodium silicate

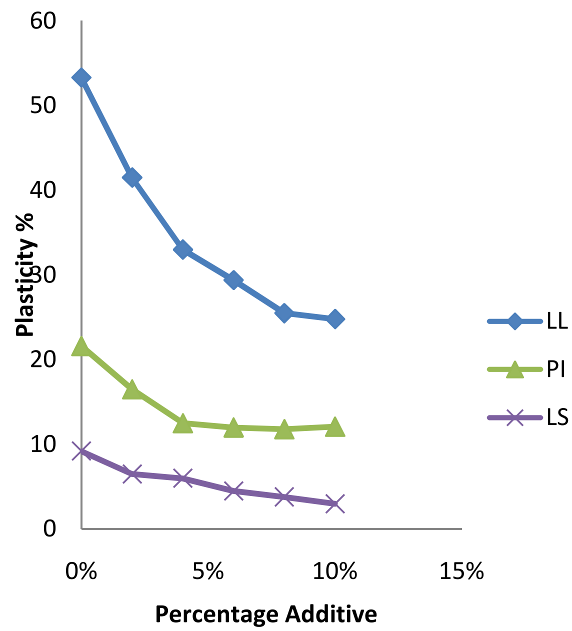


FIG 6: A graph of soil plasticity against % Additive with Sodium silicate for Numan-Jalingo soil samples

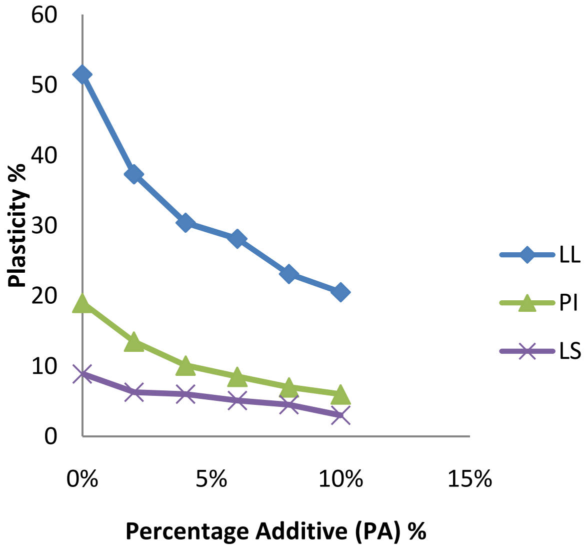


FIG 7: A graph of soil plasticity against % Additive using sodium