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Beneficial Use of Class N Pozzolana on Some Geotechnical Engineering Properties of Black Cotton Soil for Construction of Flexible Pavement.

Faustinus Bayang[1*], Haruna Garba[2], John E. Sani[3], Eze O. Chika[4].
(Corresponding Author 1,2,3,4) Nigerian Defense Academy, Kaduna, Nigeria.*

ABSTRACT: *This study was carried out to evaluate the effect of Class N Pozzolana (Metakaolin) on some geotechnical engineering properties of North eastern Nigerian black cotton soils. Laboratory tests were performed on the natural and Metakaolin treated soil samples in accordance with BS 1377(1990) and BS 1924(1990).Treated specimens were prepared by mixing the Soil with Metakaolin (MKL) in steps of 0, 4, 8, 12, 16, 20 and 24% by dry weight of soil. The preliminary investigation carried out on the natural black cotton Soil found in Yamaltu/Deba, Gombe State, Nigeria shows that it falls under Clayey material of A-7-6 (16) using AASHTO classification and inorganic Clay material CH according to unified Soil classification system (USCS). The specific gravity of the Soil samples increased from 2.30 for the natural Soil to 2.42 at 24% Metakaolin content. The liquid and plastic limits decreased and increased respectively from 79.00% and 27.97% to 59.00% and 31.24% both at 24% Metakaolin content. The maximum dry density (MDD) of the Soil increased from 1.41mg/m3 for the natural Soil to a peak value of 1.46mg/m3 at 24% Metakaolin (MKL) content. The Optimum moisture content (OMC) decreased from a value of 30.90% for the natural Soil to 26.0% at 24% Metakaolincontent.The soaked California bearing ratio (CBR) values from 4% Metakaolin and above did not meet the minimum CBR value of 30% specified by (Nigerian General Specification, 1997) as subbase material. However, the peak CBR value of 8.12% was recorded at 24% Metakaolin (MKL) content. The improvement in some of the geotechnical properties of the black cotton Soil observed were not adequate enough for its use in road work. However, MKL can be used as an admixture in the stabilization of black cotton Soil with Cement or other additives.*

KEYWORDS: *Class N Pozzolana , Black Cotton Soil, Flexible Pavement, Compaction characteristics, California Bearing Ratio , Atterberg Limits.*

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I. INTRODUCTION

Black Cotton Soils are the most Problematic Clays due to their peculiar swell shrink behavior with fluctuations in moisture Content. Considerable surface area of most of the World nations is covered by the Black Cotton Soil and huge damages caused by them are also reported by (Chen F.H, 1988; Katti R.K; Katti A.R, 1994).The Soils are formed under conditions of poor drainage from basic rocks or limestone under alternating wet or dry climatic conditions.These soils usually exhibit shrink-swell characteristics with surface cracks, opening during the dry seasons which are more than 50mm or more wide and several mm deep.These cracks close during wet season and as a result of these variations,vertical movement takes place within the soil mass which lead to failure of pavement in the form of settlement,heavydepression,cracking and unevenness.(Osinubi K.J, 1997).These soils also cause more damage to structures, particularly light buildings than any other natural hazard, including earthquakes and floods (Jones D.E and Holtz W.G (1997). Nigeria is one among these countries where expansive soils cover as much as an estimated area of 104,000km^2 in the North eastern part.(Ola

S.A. 1983). The black cotton soils of north eastern Nigeria derive their origin from basalts of the upper Benue through which covers a wide range extending north and east of the Jos plateau and from quaternary sediments of lacustrine origin from the chad basin consisting mainly of shales,clay and shaly sediments (NBBRI, 1983). Specifically, Nigerian black cotton soils are formed from weathering of shaly and clay sediments and basaltic rocks. According to (Ola S.A. 1983), the Nigerian black cotton soils contains more of the Montmorrillonite clay mineral with subsequent manifestation of swell properties and expansive tendencies. The distinct dark-grey to black color of this soil is due to the presence of iron and titanium in some quantity and Cotton thrive well in these soils commonly. Owing to these facts the amount of damages caused by expansive Soils is alarming. In Nigeria, the damages caused by these soils are not documented; however, the annual cost of damage to Civil engineering structures is estimated at $1000 million in the USA, £150 million in the UK, and many billions of pounds worldwide (Gourlely C.S et al,1999).

A large volume of waste materials from agricultural, domestic, industrial and mineral sources are been generated daily and the safe disposal of these wastes is increasingly becoming a major problem and concern around the world (ETL 1110-3-503,1999). Metakaoilin is a highly pozzolanic, reactive and supplementary cementatious material that conforms to (ASTM C618-05 (AASHTO M295) specification. It is unique in that it is neither the by product of an industrial process nor is it entirely natural. Metakaolin is derived from naturally occurring mineral and is manufactured specially for cementing applications; it is refined kaolin clay that is fired (calcined) under carefully controlled conditions to create an amorphous aluminosilicate that is reactive in concrete and is obtained by calcination of the kaolinitic clay at temperatures between 600 – 800°C (Equ. 1).(Salvador S.1995; Varga G, 2007). The chemical equations describing this process is

$$AL_2Si_2O_5(OH)_4 \quad 600 - 800\,^0C \quad AL_2O_3.2SiO_2 + 2H_2O \qquad (1).$$

Kaolin **Heat** Metakaolin

II. MATERIALS AND METHODS.

MATERIALS.

Soil : The soil sample used in this study (dark grey in colour) was obtained along the Gombe-Biu road in Yamaltu/Deba Local Government Area of GombeState,Nigeria, using the method of disturbed sampling. The location falls between Latitude $10^o\ 12^I$ N and Longitude $11^o\ 23^I$ E.

Metakaolin : The Kaolin used for the production of the Metakaolin was obtained locally from Chikun Local Government Area of Kaduna State, Nigeria and heated to 600 – 800°C in a Kiln of the Kaduna Bricks and Clay products Limited,KM 15, Kachia road, Kaduna, Nigeria. According to ASTM C618 (2005), the minimum amount of SiO_2, AL_2O_3 and Fe_2O3 that needs to be present in a class N Pozzolan is 70%. From the Oxide composition of the Metakaolin used as shown in Table 2; and as determined by the method of Energy dispersive X-Ray Flourescence (XRF) of the Nigerian Geological Survey Agency, Kaduna, Nigeria. From the Oxide composition the amount of these compounds is approximately 95%, this is an indication that the material is highly reactive.

METHODS.

Laboratory tests were conducted to determined the index properties, compaction and strength characteristics of the natural and Soil- Metakaolin mixtures in accordance with BS 1377(1990) and BS 1924(1990) respectively.

III. RESULTS AND DISCUSSIONS.

Effect of Metakaolin on the index properties, compaction and strength characteristics of the black Cotton soil.

The index properties of the natural Soil show that it is an A-7-6 Soil according to AASHTO classification system (AASHTO,1986),Clay with high plasticity (CH),using the unified Soil Classification System, USCS (ASTM,1992) and high swell potential, Nigerian Building and Research Insitude.(NBRRI,1983).The soil has a liquid limit value of 79.00%, plastic limit of 21.00%, plasticity index of 58.00%, linear shrinkage of 21.00% and a specific gravity of 2.30 with 96.00% of the soil passing the BS no 200 sieve (0.075mm aperture). The predominant clay mineral is montmorrillonite. The properties of the natural soil are summarized in Table 1, while its particle size distribution curve is shown in figure 1.The specific gravity; Gs of the Metakaolin used in this study is 2.70 and its Oxide composition is given in Table 2.; with its physical properties shown inTable 3.

Specific gravity:The Specific gravity of soil particles is the ratio of the weight in air of a given volume of Soil particles to the weight in air of an equal volume of distilled water at a stated temperature. Specific gravity is an important parameter used in the computations of many Laboratory tests on Soils. It is required in the calculation of the void ratios of Soil specimens, in the determination of the moisture content by the Pycnometer method and the Particle size analysis (Sedimentation test) (O,Flaherty,1974). As shown in Fig.2 below the values of the specific gravity of the Soil-MKL mixes increased steadily from a value of 2.30 for the untreated black cotton soil to 2.42 at 24% MKL content. This increase in Specific gravity is due to the higher specific gravity value of Metakaolin (2.70) compared to the virgin Soil.

Atterberglimits . The results of Atterberg limits test of the natural and treated Soil with different percentages of MKL. is depicted in Fig.3. The results of the treated Soil showed that the Liquid and plastic limits decreases and increases respectively,as the MKL increases. The natural Soil has liquid and plastic limits of 79.00% and 27.97%. These decrease and increase to about 59.00% and 31.24% with addition of 24% MKL. The liquid limit of the black cotton Soils is essentially controlled by the thickness of the diffused double layer and the shearing resistance at particle level. The addition of the MKL content results in the decrease of the liquid limit due to the effect of reduction in the diffused double layer thickness as well as due to the effect of dilution of clay content of the mix.

For the plastic limit and as shown in fig.4. there was an initial decrease from 27.97% for the natural black cotton to 24.44% at 4% MKL and thereafter the plastic limit increased to 31.24% at 24%.This alteration of soil character probably occurred due to bivalent calcium ions supplied by the MKL replacing less firmly attached monovalent ions in the double layer surrounding the clay particle. But with higher doses of MLK, there was a corresponding increase in the plastic and this could be due to the increase in the amount of fines content. The reduction and increase in the liquid and plastic limits is accompanied with a corresponding decrease in the plasticity index of the soil as shown in fig.4. The changes may probably be due to cation-exchange reaction that predominate the early stages of the admixed soil which resulted in the agglomeration and flocculation of the clay particles. This is consistent with Osinubi and Katte 1977, Uche and Abubakar (2010) works. In fig. 4. linear shrinkage decreased from 17.57% to 11.50% with increase MKL content from 0% to 24%. This may be attributed to the replacement of the soil fines by MKL. The later is less in activity with changes in moisture content and therefore, reduced the linear shrinkage of the Soil-MKL mix. This enhances volume Stability of the soil.

Maximum dry density : The variation of maximum dry density (MDD) of the black cotton soil with Metakaolin (MKL) content is shown in Fig.5. The MDD increase continuously with higher MKL content. This increase in MDD could be due to MKL occupying the voids within the soil matrix as well as the flocculation and agglomeration of the clay particles due to exchange of ions (Yoder E.J. 1975; Osinubi K.J.). This trend is in agreement with the findings reported by (Lees et al, 1982; Lorliam A.Y. et al, 2012; Ola S.A, 1991). Also, the increase in MDD was due to the comparatively high specific gravity value of 2.70 of the Metakaolin compared to that of the black cotton soil which is 2.30.

Optimum moisture content : Fig.6. shows the variation of Optimum moisture content (OMC) with Metakaolin (MKL) content. The result shows that the OMC decreased with increase in MKL content. This trend may be attributed to the fact that replacement of soil with MKL content reduces the attraction of water particles. An explanation for this trend was the decrease in OMC with increase in MKL content might be due to cation exchange reaction that caused the flocculation clay particles. This result is in agreement with the findings reported by (Ola S.A,1978; Gidigasu M.D. 1976).

STRENGTH CHARACTERISTICS.

California bearing ratio : Fig.7. shows the variations of soaked CBR of MKL treated black cotton soil.The CBR value of the natural soil was 2%. At 24% MKL content, a CBR value of 8.12% was obtained. This showed a marginal improvement. The reason for the slight improvement in the strength could be due to the inadequate amounts of calcium silicate hydrate (CSH), which is the major element for strength gain. It has been recommended that the CBR value of 180% should be attained in the laboratory for cement-stabilized material to be constructed by the mix-in-place method (Nigerian General Specification,1997). Although,the MKL treated black cotton soil did not meet the minimum criteria as specified (Nigerian General specification,1997) for materials suitable for use as base course material of not less than 30% CBR determined at mdd and omc, the MKL could be used in admixture stabilization with a more potent stabilizer in order to reduce the cost of stabilization in construction work

IV. CONCLUSIONS

From the results of tests conducted on the natural and Metakaolin treated black cotton Soil the following conclusions were drawn:

* The black cotton soil used in this study is classified as an A-7-6(16) or clay with high plasticity (CH).
* The MKL decreased the liquid limit from 79.00% to 59% at 24% MKL, the plastic limit decreased from 27.97% to 24.44% at 4% MKL and thereafter increased to 31.24% at 24% MKL content. The plasticity index decreased from 51.03% to 28.76 at 24% MKL content. None of the values of plasticity indices met the 12% plasticity index specified by clause 6201 of the Nigerian General Specification (1997) for sub base material.
* The CBR of the MKL treated black cotton soil did not improve considerably. The increase recorded was marginal to a peak value of 8.12% at 24% MKL. The CBR obtained is less than the minimum range of 20-30% specified by (Nigerian General Specification, 1997) for subbase material.
* Maximum dry density (MDD) increased, while the Optimum moisture content(OMC) decreased steadily with increase in MKL content.
* The Specific gravity; Gs increased steadily from 2.30 for the natural soil to a value of 2.42 at 24% treated black cotton soil.

Further research be carried out and the MKL should be used as an admixture with a more potent stabilizer(cement,lime) for use as a Flexible Pavement material as its benefits would greatly reduce cost of stabilization.

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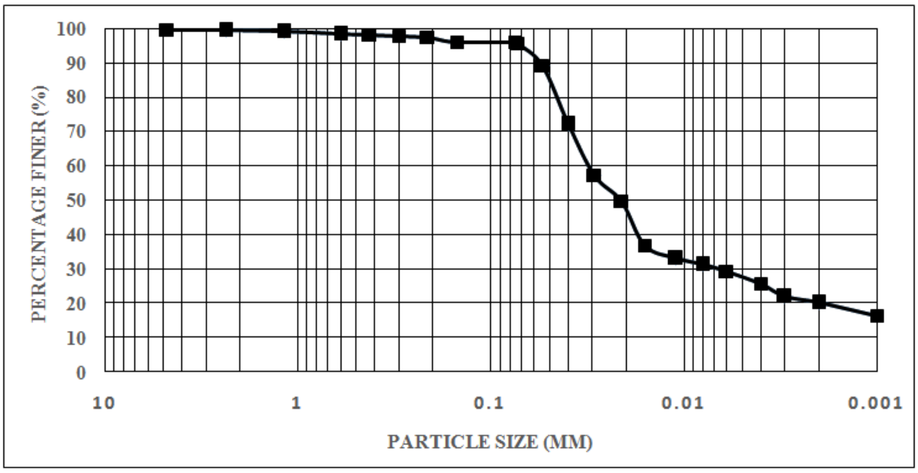

Figure1: Particle size distribution of the natural soil.

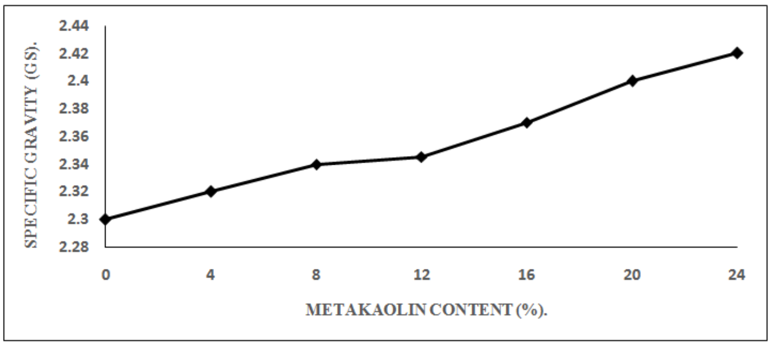

Figure2: Variation of Specific gravity of soil with Metakaolin content (%).

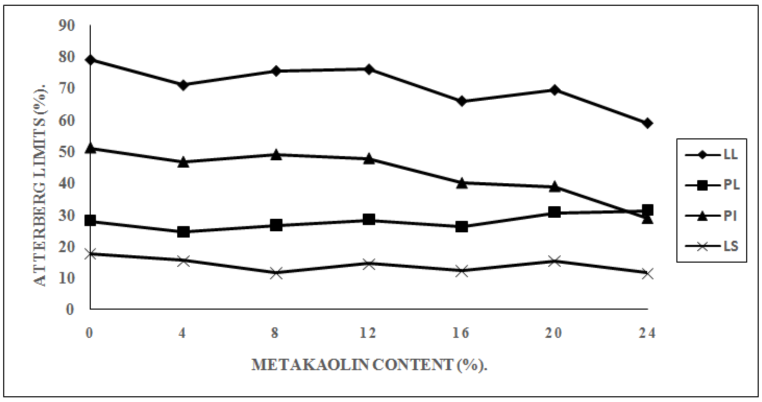

Figure3: Variation of Atterberg limits of soil with Metakaolin content (%).

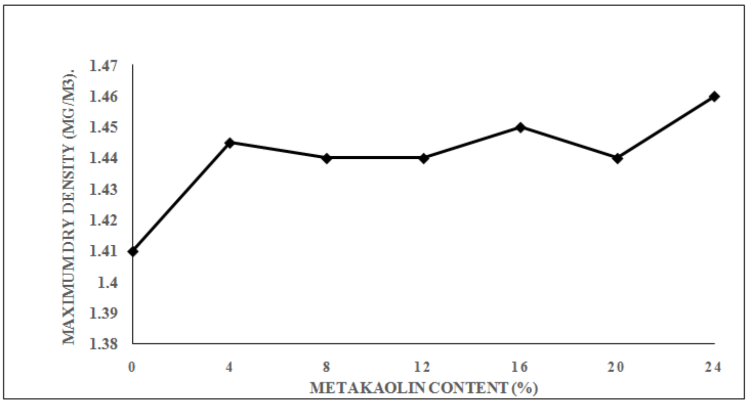

Figure4: Variation of Maximum dry density of soil with Metakaolin content (%).

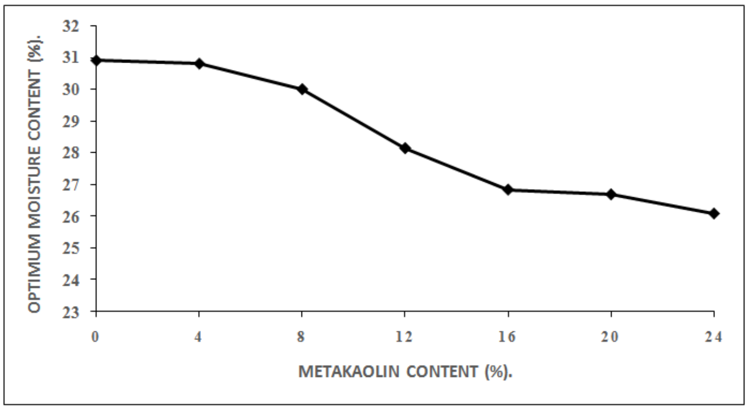

Figure 5: Variation of Optimum moisture content of soil withMetakaolin content (%).

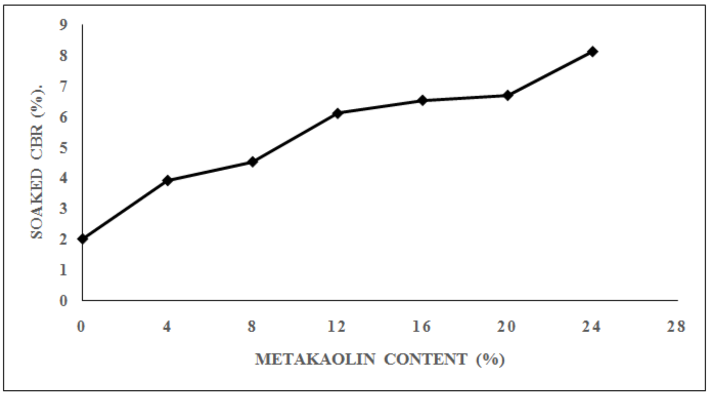

Figure 6: Variation of California bearing ratio of soil with Metakaolin content (%).

Table 1:**Properties of the natural black cotton Soil.**

Property	Quantity
Percentage passing BS No 200 Sieve (%)	96.00
Natural moisture content (%)	15.00
Liquid Limit (%)	79.00
Plastic Limit (%)	21.00
Plasticity index (%)	58.00
Linear Shrinkage (%)	21.00
Free Swell (%)	90.00
Specific gravity	2.30

AASHTO Classification	A-7- 6
USCS	CH
NBRRI Classification	High swell potential.
Group index	16
Maximum Dry Density (mg/m^3)	-
British standard light (BSL)	1.41
Optimum Moisture Content (%)	-
British standard light (BSL)	30.60
Ph	7.2
Colour	Dark grey
Dominant Clay Mineral	Montmorillonite.

Table 2: Oxide Composition of Metakaolin used.

Oxide	Concentration (%).
Sio_2	57.32
Al_2o_3	23.70
Fe_2o_3	14.03
CaO	0.38
MgO	0.94
SO_3	ND
L.O.I.$^{\Delta}$	1.18
Na_2O	0.38
K_2O	0.65
TiO_2	1.30
P_2O_5	ND
MnO	0.03

Δ = Loss on ignition. ***ND = Not detected.**

Table 3: Physical Properties of Metakaolin.

Property	Value
Specific gravity	2.70
Fineness	75µm passing
Bulk density (g/cm^3)	1.22
Colour	Reddish brown.
Specific surface area (m^2/g)	850
Physical form	Powder

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