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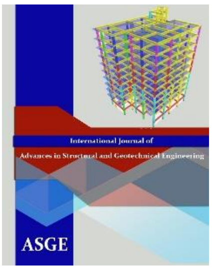

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Improvement of Geotechnical Properties of Clay Soil Using Metakaoline

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ABSTRACT

Problematic soils pose a serious challenge to geotechnical engineers when construction activities are to be carried out in/on them. Therefore this paper aims at studying the improvement of the geotechnical properties of this type of soil using Metakaolin through laboratory studies. The soil samples used were mixed with 0% to 20% Metakaolin at an interval of 5%. The prepared samples were subjected to Atterbarg limits, Compaction, California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests. The results obtained have shown that the maximum addition of the Metakaolin upon which a maximum stabilization was observed was 5% and above which there was no significant changes in the soil properties. A decrease in the liquid limit and plastic limit of the soil from 26.8% and 21% for the control to 25.7% and 20.8% were respectively observed at 5% Metakaolin. The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the clay soil also changed from 13% and 1.84 Mg/m^3 at 0% Metakaolin to 8.2% and 2.18 Mg/m^3 at 5% Metakaolin. The soaked CBR value increased from 12.73% to 15.33% and the un-soaked CBR value also increased from 16.56% to 17.77%. The UCS of the soil increased with an increase in curing period up to 28 days, with a maximum value of 624 kN/m^2 which was obtained at 5% Metakaolin. This has therefore shown that the improved soil could be used in the preparations of soil sub-grade and sub-base road constructions, especially in low traffic roads as the results obtained have met the specifications of such roads in Nigeria.

Keywords: *Problem soil, Clay soil, Metakaolin, Soil stabilization.*

1.0 INTRODUCTION

Soils are common and most significantly used civil engineering materials. They are used either as foundation to receive loading of structures or sometimes used in the construction of infrastructures such as embankment, retaining walls, roads, tunnels etc. Although the type of soil depends on the parent rock type, its mineral constituents and the climatic regime, the occurrence and distribution of soil in nature varies from location to location [1]. Clay soil is commonly encountered in civil engineering constructions and is predominant in most of the subgrade soil materials of Nigeria [2]. It poses some construction problems due to low compressive strength and excessive settlement which consequently lead to low bearing capacity values when wet and severe cracking when dry [3,4], thus causing instability that leads to severe distress and damage of the overlying structure [5].

Rapid development and urbanization had prompted many people to construct in many areas covered by clay soil. This eventually results in severe cracks which could render the constructed structures unsafe for use. In some instances civil engineers do stabilize these soils before building over them. For the stabilization, several methods were employed ranging from the used of cement, lime, fly ash and bitumen, to the use of agricultural wastes such as rice husk ash.

Metakolin is the product obtained by the calcinations of kaolinite clay at moderate temperature (650 - 800°C) [6]. The high pozzolanic activity and supplementary cementitious additive present in metakaolin have attracted considerable attention from many researchers [7-8], this is because they significantly enhance performance characteristics of concrete and other related products. For instance, Muduli, and Mukharjee replaced cement with 0%, 5%, 10%, 15% and 20% metakaolin, and concluded that it was feasible to produce sustainable concrete by using maximum waste concrete i.e. 100% recycle concrete aggregate and 15% metakaolin without much affecting the strength criteria [9]. Similarly, Radonjanin et al. has revealed that the use of 10% metakaolin in recycled coarse aggregate exhibited considerable property enhancement in terms of compressive strength, STS, modulus of elasticity and workability [10].

Kaolinite, from which metakaolin is produced is readily available in commercial quantity in many places in Nigeria. According to RMRDC [11], about three billion metric tonnes of kaolin is estimated to be deposited in various parts of Nigeria notably in Adamawa, Borno, Abia, Delta, Ekiti, Kaduna, Katsina, Kogi, Ogun, Ondo, Oyo, and Plateau States.

The potential of using metakaolin as partial replacement of cement in concrete is fully harnessed. Cement is one of the materials perfectly used in stabilizing clay soil. However, there is no much work done to investigate the possibility of using metakaolin to stabilize clay soil. It is on this framework, this study was conceived. This paper therefore presents the laboratory test results of the investigation in to the effect of metakaolin on the engineering properties of clay soil, through the conduct of atterberg limits, compaction, California bearing ratio (CBR) and unconfined compressive strength (UCS) tests.

2.0 MATERIALS AND METHOD

2.1 Materials

The materials used in this study were clay soil and metakaolin.

2.1.1 Clay Soil

The materials used in this study include the clay soil and metakaolin. The clay soil samples were obtained from Bayero University Kano behind Electrical Engineering Department (11° 58’22.54”N and Longitude 8° 25’27.95”E) by disturbed sampling method. The samples were collected at a depth of about 0.45 m below the ground surface to avoid organic matter. The soil samples were air-dried before lumps were broken to obtain particles passing BS No. 4 sieve (4.75 mm aperture) used for the tests.

2.1.2 Metakaolin

The metakaolin used in this study was obtained by thermal treatment of the selected kaolin in a suitable condition, i.e. subjecting it to burning at a predetermined temperature (650°C). The kaolin from which metakaolin was formed was originally sourced from local miners in Kankara, Katsina State, Nigeria. The chemical composition of the clay was reported by [12] and it contains majorly of SiO_2 (48.86%), Al2O3 (37.83%). It also possessed other oxides of about 1.5% and loss on ignition (LOI) of 11.81%. The chemical composition of the metakaolin was determined by using the method of x-ray fluorescence and is presented in Table 1.

Table 1: Chemical composition of the metakaolin

Oxide composition	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	K_2O	L.O.I.
Quantity (%)	52.53	39.18	4.35	0.30	0.21	0.23	0.03	0.3	2.87

From Table 1, the sum of SiO_2, Al_2O_3, and Fe_2O_3 content of the metakaolin is 96.06%. ASTM C618 recommended that a material is characterized as a natural pozzolan, once the sum of the three compounds exceeds 70% [13]. Therefore, Table 1 confirmed that the metakaolin used in this study is a natural pozzolan.

2.2 Methodology

Series of laboratory tests were performed to determine the index and engineering properties of the natural clay soil and metakaolin treated clay soil in accordance with BS 1377[14]. The laboratory tests performed include the atterberg limits, compaction, CBR and UCS.

The compaction, CBR and UCS tests were performed using the British Standard light (BSL) compactive effort. The tests were conducted on natural soil and the stabilized soils at stepped concentration of 5%, 10%, 15% and 20% metakaolin content by dry weight of soil, except for the UCS where the percentage mixing was limited to 5% and 10%. This was because the maximum values obtained from compaction and CBR tests did not exceed 10%.

For CBR and UCS tests, the specimens were prepared at their optimum moisture content. The samples were cured for 24 and 48 hours before testing for CBR and for 7, 14 and 28 days in the case of UCS in accordance with [15].

3.0 RESULTS AND DISCUSSION

3.1 Index properties

The summary of the index and engineering properties of the natural soil are presented in Table 2. The particle size distribution curve of the soil is presented in Figure 1 and the soil sample was classified as A-7-6 (3) in accordance with [16] and Clay of low to medium plasticity (CL) in accordance with [17]. These findings are in good agreement with those obtained by [18] on similar soil sample obtained around the same location.

Table 2: Properties of the natural clay soil

Property	Value
Liquid limit (%)	26.8
Plastic limit (%)	5.8
Plasticity index (%)	21
Linear shrinkage (%)	3.93
Specific gravity	2.63
Percentage passing No. 200 sieve (%)	53.9
AASHTO classification	A-7-6
Group Index	3
USCS classification	CL
Maximum Dry Density (MDD) BSL (Mg/m^3)	1.84
Optimum moisture content (OMC) (%)	13
Unconfined compressive strength (kN/m^2)	176
Un-soaked California bearing ratio (%)	16.53
Soaked California bearing ratio (%)	12.73

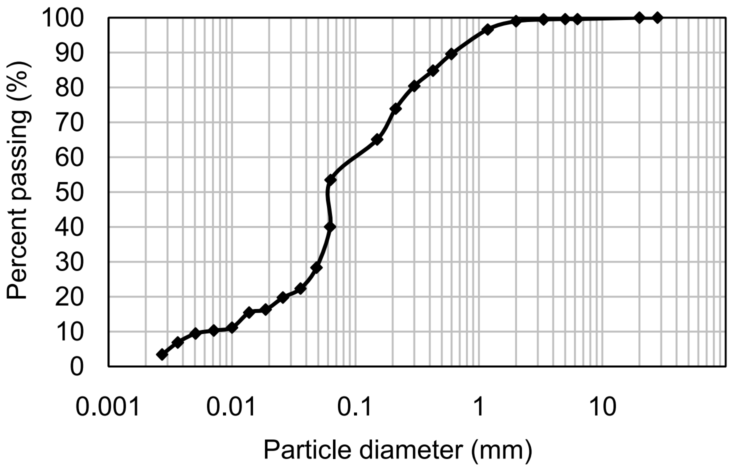

Fig. 1: Particle size distribution curve of the clay soil

3.2 Atterberg limits

The variation of the liquid limit, plastic limit and linear shrinkage of the clay-metakaolin stabilized clay soil is presented in Figure 2. It can be seen from this Figure that there is a slight increase in the liquid limit of the stabilized soil with an increase in metakaolin content, whereas the plastic limit slightly decreased with increasing metakaolin content. This could be attributed to the filling of voids in the clay soil matric with metakaolin which could eventually prevent moisture from percolating the soil. Generally, the variation in the liquid and plastic limits of the clay soil mixed with metakaolin was more or less instantaneous, the clay particles when mixed with metakaolin undergo flocculation to form aggregates. The aggregates formed behave like particles of silt. Similarly, the linear shrinkage slightly decreased with an increase in the metakaolin content of up to 10%.

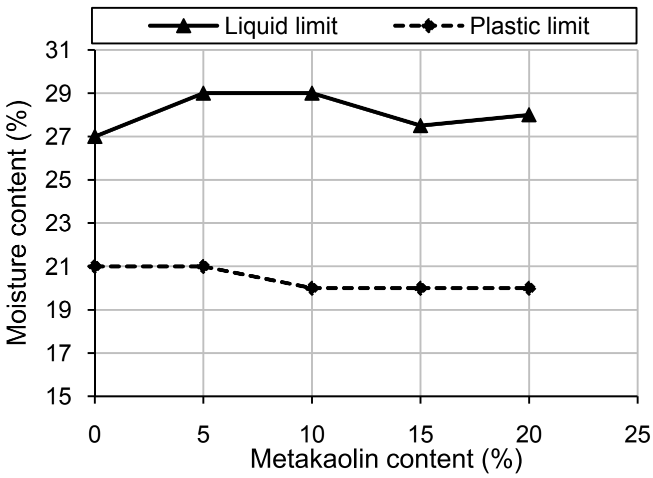

Fig. 2. Variation of atterberg limits with metakaolin content

The variation in the linear shrinkage of the clay soil mixed with metakaolin is presented in Figure 3. The shrinkage limit slightly decreased with an increase in the metakaolin content of up to 10%. The decrease in the linear shrinkage helps in decreasing the potential for swelling. The reduction in swelling is believed to be mainly due to substitution of cations in the clay soil by calcium. The reduction in swelling also means that there is a decrease in moisture absorption in metakaolin-treated clay soils. These findings are in agreement with [19] on lime stabilization of clay minerals and soils.

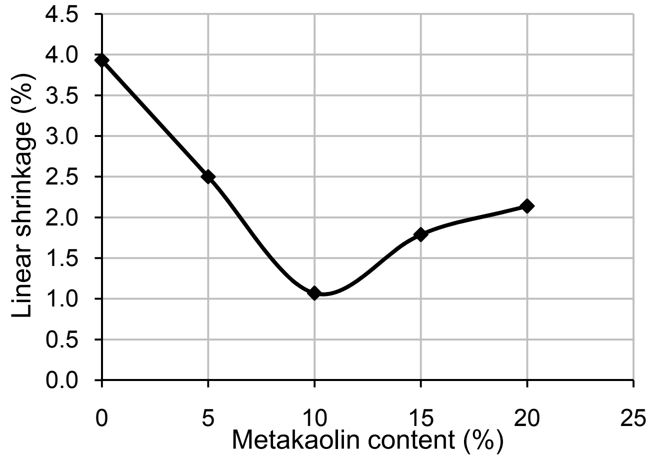

Fig. 3. Variation of shrinkage limit with metakaolin content

3.3 Compaction characteristics

The variations in maximum dry density (MDD) and optimum moisture content (OMC) of clay soil mixed with metakaolin are shown in Figure 4. It can be observed that the MDD increased with an increase in metakaolin content of up to 5% and subsequently decreased with increasing metakaolin content from 5% to 20% for the rest of the experiment.

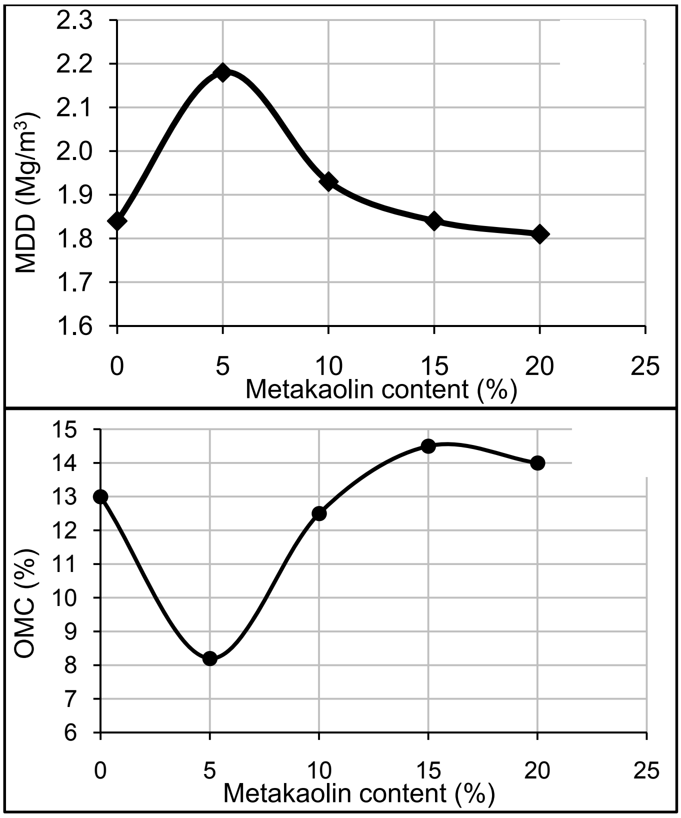

Fig. 4. Variation of (a) maximum dry density and (b) optimum moisture content of clay soil – metakaolin mixture

On the other hand, the OMC decreased with an increase in metakaolin content of up to 5% and subsequently increased with increasing content of the metakaolin for the rest of the experiment. The increase in MDD up to 5% could be as a result of filling of the voids within the soil matrix by the metakaolin and also the flocculation and agglomeration of the clay particles due to cation exchange [20]. Similarly, the decrease in OMC could be due to large amounts of water required for the hydration of the clay soil-metakaolin mixtures. It could also be due to the increase in fine content from the metakaolin which results in larger surface areas that require more water to react. This observation is consistent with that reported by other researchers for other stabilized clayey soils [21-23].

3.4 Strength characteristics

The strength characteristics of the clay soil – metakaolin mixture was assessed using CBR and UCS tests results.

3.4.1 California Bearing Ratio (CBR)

The variations in un-soaked and soaked CBR values of the clay soil – metakaolin mixture are presented in Figure 5. Although the natural soil possessed low un-soaked and soaked CBR values of 16.53% and 12.73% respectively for the standard Proctor. It can be seen that there is an appreciable increase in CBR values with increasing metakaolin content of 5%. Maximum CBR values of 17.90% and 15.30% for the unsoaked and soaked conditions were respectively obtained at 5% metakaolin content. The soaked CBR value of 15.30% obtained is adequate to be used as subgrade but slightly lower than the recommended CBR for sub-base courses [15]. Although the CBR is low but it can be used for subbase of light traffic roads.

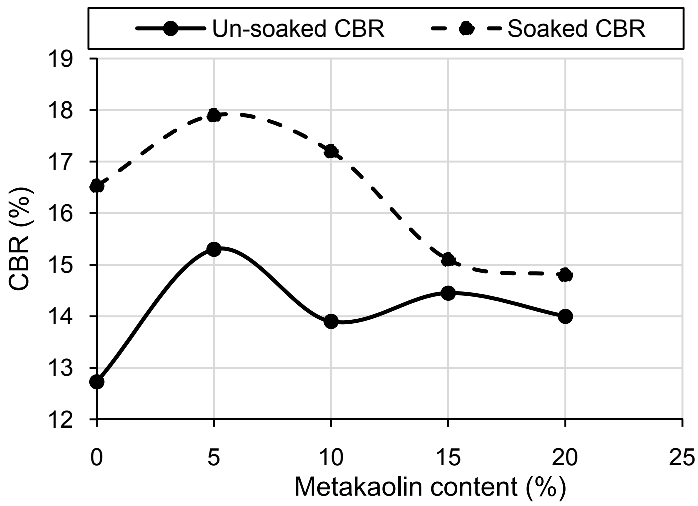

Fig. 5. Variation of CBR of clay soil – metakaolin

3.4.2 Unconfined Compressive Strength (UCS)

The variations in UCS of clay-metakaolin mixture cured for 7, 14 and 28 days period is shown in Figure 6. Increase in the UCS values were observed with increase in metakaolin content and curing periods as shown in Figure 6. The increase could be mainly due to the formation of cementitious compounds of calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) which are responsible for strength development [24]. Similarly, the increase in UCS with curing period can be attributed to time dependent gain in strength due to the hydration reactions of the clay soil and metakaolin [22]. According to [25], an increase in the UCS of 345 KN/m2 or more must be achieved for treatment to be considered effective. Therefore the maximum UCS value of 624 kN/m^2 obtained at 28 days curing has satisfied this ASTM criteria.

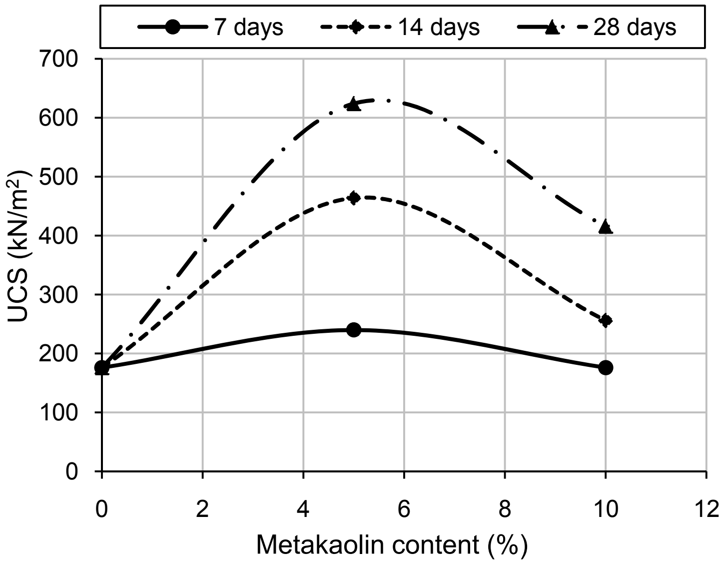

Fig. 6. Variation of UCS of clay soil – metakaolin

4.0 CONCLUSIONS

The clay soil used in this study has been classified as A-7-6 and CL in the AASHTO soil classification system and Unified Soil Classification System (USCS), respectively. The maximum stabilization was obtained at 5% addition of metakaolin. Compaction characteristics of the clay soil generally followed the trend of increasing MDD and corresponding decrease in OMC with higher metakaolin contents. The peak CBR value of 15.30% obtained at 5% metakaolin addition can be used in subgrade construction without any capping layer and subbase course of light traffick roads. The peak UCS values of 624 kN/m^2 obtained at 28 days curing has satisfied the ASTM criteria.

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