Effect of Compaction Delay on Metakaolin Stabilized Lateritic Soil for Highway Construction

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Abstract- The research investigate the effect of delay in compaction of soil stabilized with 10 percentage of metakaolin for highway construction. The physical properties tests on the natural soil classify the soil as A-2-7 soil according to Association of State Highway Transport Officials (AASHTO) and Well Graded Clay Sand GW according to Unified Soil Classification System (USCS) and mechanical tests was conducted on both natural and stabilized soil. However, the stabilized soil was delayed for 2, 4, 6, 8 and 10 hours to evaluate the influence of compaction delay on the treated soil samples. The compaction characteristics on the natural soil were 1.83 Mg/m^3 and 9.6% for MDD and OMC respectively. The strength properties on the stabilized soil shows a declined as compaction delays increases. At 7-day UCS the maximum value for the BSH energy level was 747KN/m^2, and the CBR was 43% un-soaked and 39% for Soaked CBR after a 2-hour delay. Since stabilization using 10% metakaolin and a compaction delay of more than 2 hours reduces the soil's strength, the impact of another stabilizing agent in addition to metakaolin can be examined further.

Indexed Terms— Metakaolin, Compaction Delay, Highway, CBR, UCS

I. INTRODUCTION

The over-reliance on industrially produced additives such as cement, lime, and bitumen has kept the cost of construction of a stabilized road financially high (Oriola and Moses, 2010). However, the constraint in the availability of standard base course materials may be overcome by designing the road to fit the substandard site material by the application of additives which are normally mixed with soil in predetermined economical proportions to achieve favourable improvement of soil properties. Studies have shown that metakaolin contain high silicon oxide which made it highly pozzolanic material that can be adopted to stabilize soils (Alabadan et al., 2006 and Umar et al., 2015). Metakaolin is not a byproduct of an industrial process; it is produced from a naturally occurring mineral and is produced especially for cementing purposes. The chemical investigation of metakaolin performed by Umar et al. (2015), shows that: SiO_2 -53.7%, Al_2O_3 -34.2%, Fe_2O_3 -3.84%, CaO-0.513%. Metakaolin has the ability to increase strength of concrete or soil when mixed, such that the Calcium hydroxide accounts for up to 25% of the hydrated Portland cement; although the calcium hydroxide does not contribute significantly to the strength or durability of concrete (Poon et al., 2002; Mindness et al., 2003). Most lateritic soils in their natural states are at best suitable mainly as sub-base course materials where roads are expected to carry heavy wheel loads. Ola (1974) and Akoto (1987) found that failures of roads are due to the defective nature of lateritic soils which are the commonly available material for base and sub-base construction.

However, delays in soil compaction cause changes in strength and characteristics of the soil. The majority of the time delay is inevitable due to any of the following factors: sudden rains, breakdown of machines, inadequate transportation, and so on. These extra hours have a substantial impact on the strength of stabilized soils. As a result, the effect of compaction delay between mixing and compaction on the engineering properties of lateritic soil stabilized with Metakaolin must be examined.

II. STABILIZATION BY COMPACTION

Compaction is the process by which soil is forced to pack more tightly together by reducing the quantity of air trapped in the spaces of soil mass. By compacting under controlled conditions, the air voids in well-graded soils can be almost eliminated and the soil can be brought to a condition where there are fewer tendencies for subsequent change in volume to take place. Therefore, compaction is a process which gradually induces artificial saturation or a state of zero-air voids. However, thus is a theoretical situation because it is practically impossible to expel all the air voids present in the soil. The fact is that loose material may be made more stable simply by compacting it. In other words, compaction of soils densifies, stabilizes and increases its strength. Compaction plays a fundamental role on the properties even stabilize materials.

Compaction is measured quantitively in terms of dry density of the soil, which is the mass of the solid per unit volume of the soil in bulk. The moisture content of the soil is the mass of water contained and expressed as a percentage of dry soil. The amount of compactive effort used and the moisture level of the soil, which hydrates the soil particles, determine the increase in dry density caused by compaction. Each soil has its own unique optimum moisture content and the value depends mainly on the amount and type of plastic fines that it contains. However, the optimum moisture content largely depends on the compactive effort and the term always need to be considered in relation to the type of compaction test used to define the property. Purposefully, compaction is intended to improve the strength and stiffness of the soil. Compaction is employed in the construction of road bases, runways, earth dams, embankments and reinforced earth walls. Compaction can be applied to improve the properties of an existing soil or in the process of placing fill. The primary objectives of compaction are to enhance shear strength, bearing capacity, stiffness, reduce future settlement, voids ratio and thus permeability, thereby lowering possible frost heave. Loose soils must be compacted during the construction of highway embankments, earth dams, and many other engineering projects to improve their unit weights and strength characteristics, hence increasing the bearing capacity in support of foundations. Compaction also minimises the amount of unwanted infrastructure slumping and increases the stability of embankment slopes.

The proctor compaction adopted in the research, is a laboratory test that is commonly used to determine the maximum dry unit weight and the optimum moisture content of soils, while in the field, smooth wheel roller, sheep foot roller, pneumatic rubber-tired roller and vibratory roller are commonly used. A variety of factors influence the degree of compaction that may be obtained in the laboratory; moisture content has a significant impact on the degree of compaction achieved by a particular soil. Besides moisture content, the soil type and the compaction effort are of great effects on soil compaction. In field compaction, the desired unit weight of compaction is affected by the thickness of lift, the intensity of pressure applied by the compacting equipment and the area over which the pressure is applied. During field compaction, the dry unit weight of soil is also affected by the number of rollers passes. (Braja, 2006).

III. MATERIALS AND METHODS

3.1 Materials

The materials used for the research are presented as follows.

3.1.1 Lateritic Soil:

Lateritic soil samples were obtained from a borrow pit at Dungulbi along the Bauchi-Gombe Road using the bulk disturbed sampling method. The soil sample was collected at a depth of 1.2 m. The soil sample was wrapped and put in a polythene bag in order to prevent moisture loss. The soil samples were crushed with a mortar and pestle to remove pollutants and big particles before being air-dried at room temperature at soil mechanics laboratory of Abubakar Tafawa Balewa University, Bauchi, for around two weeks to guarantee that the soil samples were dry. Laterites' mineralogical and chemical content are determined using Silicon oxide and sesquioxides composition that lies between 1.33 to 2 (Alhassan *et. al.,* 2012). Laterites are mostly composed of quartz and oxides of titanium, zircon, iron, tin, aluminium, and manganese that persist after weathering (Tardy, 1997, Hill et al., 2000). The source rock's most prevalent relic mineral is quartz. Laterites vary greatly depending on their location, environment, and depth. Iron oxides, clay minerals, and manganese oxides are the most common host minerals for nickel and cobalt.

3.1.2 Metakaolin

The kaolin was obtained in Bauchi State, Nigeria, in the Alkaleri Local Government Area. It was prepared at the ceramic division of the Industrial Design Department's Faculty of Environmental Technology at Abubakar Tafawa Balewa University Bauchi, Nigeria. Metakaolin was created under strict circumstances in order to perfect its colour, eliminate inert impurities, and tune particle size.

The metakaolin particles are smaller than cement particles but not as tiny as silica fume. Metakaolin's quality and reactivity are greatly influenced by the properties of the raw material utilised. Metakaolin may be made from a number of kaolinite-containing primary and secondary sources which are:

- High purity kaolin deposits
- Kaolinite deposits or tropical soils of lower purity
- Paper sludge waste (if containing kaolinite)
- Oil sand tailings (if containing kaolinite)

3.2 Methods

The procedures include the following experiment in which a set 10% amount of metakaolin was added to the lateritic soil sample and the effect of delay on soil strength was assessed.

1. X-ray diffraction
2. Moisture Content
3. Atterberg Limits
   i) Liquid Limit LL,
   ii) Plastic Limit PL,
   iii) Shrinkage Limit and
   iv) Plasticity Index
4. Particle Size Analysis
5. Compaction
6. Unconfined compressive strength
7. California Bearing Ratio

3.2.2 Identification of Clay Mineral

X-ray diffraction was used to identify clay mineral in the soil sample. The small size of most soil particles prevents the study of single crystals therefore, the powder method and the orientated aggregates of particles was used. In the powder method, a small sample containing particles at all possible orientations was placed in a collimated beam of parallel X-rays, and diffracted beams of various intensities were scanned by a Geiger, proportional, scintillation tube and recorded automatically to produce a chart showing the intensity of diffracted beam as a function of angle which were converted to spacing by Bragg’s law in Equation 3.

$$n\lambda = 2d\sin\theta \qquad (1)$$

Where:

λ = Wavelength of a parallel beam of X- rays

θ = Angle parallel to the atomic planes

d = Distance between parallel planes

IV. RESULT AND DICUSSION

4.1 X-ray diffraction

The following shows the result of the X-ray diffraction carried out in order to determine the various oxide composition of the lateritic soil sample.

Table 1: Oxide Composition of the Soil Determined by X-Ray Fluorescence (XRF)

S/no.	Oxide composition	Value (%)
1.	SiO2	65.97
2.	Al2O3	23.27
3.	Ti2O	0.71
4.	Fe2O3	7.03
5.	K2O	1.06
6.	MgO	ND
7.	Na2O	0.12
8.	MnO	0.02
9.	CaO	0.44
10.	ZnO	ND
11.	NiO	ND
12.	SrO3	0.03
13.	Cr2O3	ND
14.	S	0.01
15.	P	ND
16.	NbO2	0.01
17.	MoO2	0.03
18.	Zr2O	0.02
19.	SbO	ND
20.	Cd2O	0.02
21.	Ag2O	0.01
22.	LOI	-

4.2 Natural soil

A preliminary test on the reddish-brown lateritic soil specimen found that it contains 9.6% moisture content. Table 2 summarises the natural soil properties.

Table 2: Properties of Natural Soil

S/O	Property	Quantity
1.	Colour	Reddish Brown
2.	Liquid limit %	32
3.	Plastic limits %	14
4.	Plasticity index%	18
5.	ASHTO Classification	A-2-7
6.	USCS	GW
7.	Natural moisture content %	9.6
8.	Maximum dry density (MDD)	1.96
9.	Optimum moisture content (OMC)	13.6
12.	Percentage of fine sand fraction	2.4
13.	Percentage of course sand fraction	20.0
14.	Percentage of fine gravel fraction	16.8

4.3 Particle Size Distribution

This test was performed to assess the particle size distribution of soil samples collected in accordance with British standard BS 1377:1990: part 2: 9.3. A 500 g soil sample was weighed and wet sieved using sieve No. 200 (75 m) to remove clay and silt particles.

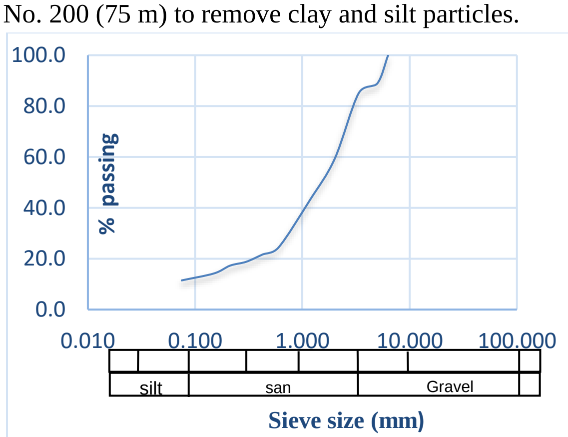

Figure 1: Particle Size Distribution

4.4 Atterberg Limits

The Atterbreg limits tests include the determination of the liquid limit, plastic limit, plasticity index and the shrinkage limit for both lateritic soil and lateritic soil stabilized with 10% metakaolin.

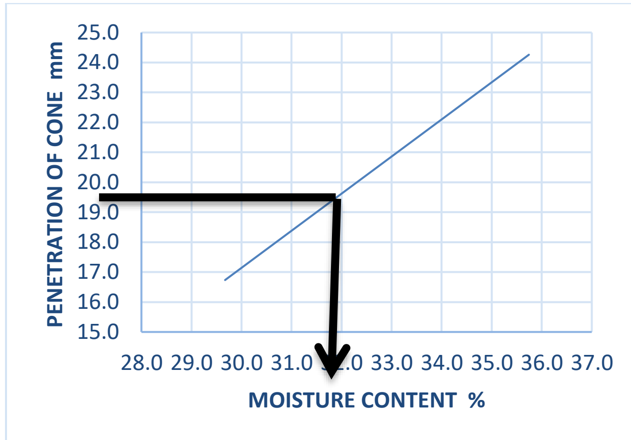

Figure: 2 Liquid limit test

The soil's was classified as A-2-7 using AASHTO classification system and well graded Clay sand GW using USCS classification.

V. COMPACTION CHARACTERISTICS

The natural soil had the highest MDD value of 1.96 Mg/m^3 when compacted with BSH Compaction, equivalent to an OMC value of 13.6%. Figure 4 depicts an increase in MDD resulting from an increase in compactive effort, with a commensurate rise in OMC. As the delay period increases, the amount of the MDDs increases as well. This demonstrated that an increase in soil dry density is a consequence of compaction energy. This assumption is consistent with the findings of previous studies of (Nwaiwu et al., 2004; Osinubi and Nwaiwu, 2005; Osinubi et al., 2006; Mohammed, 2007; Umar, 2014).

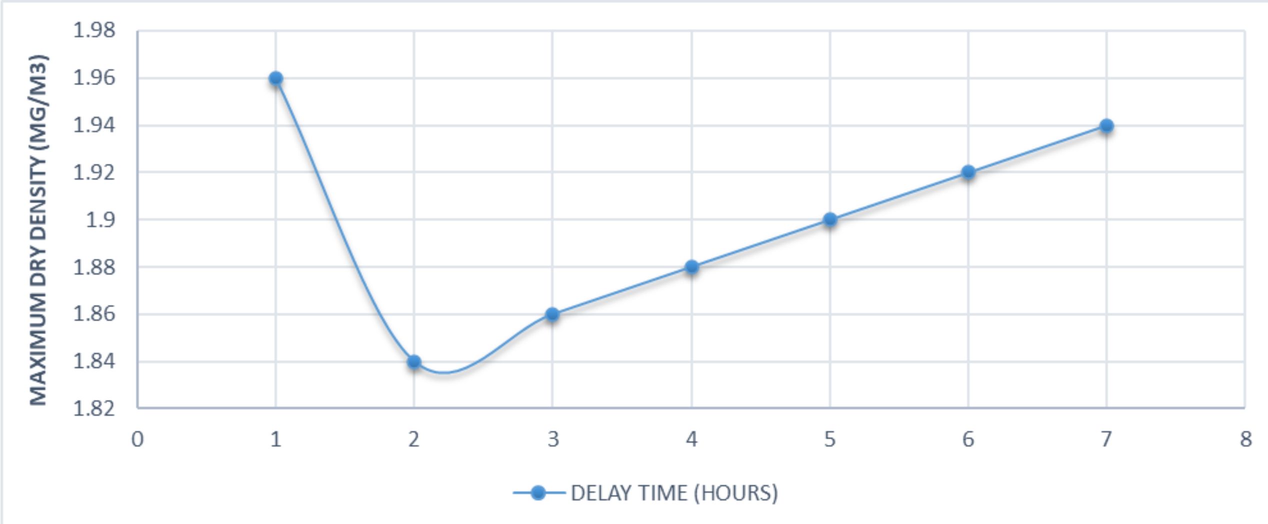

Figure 3: Variation of Maximum Dry Densities

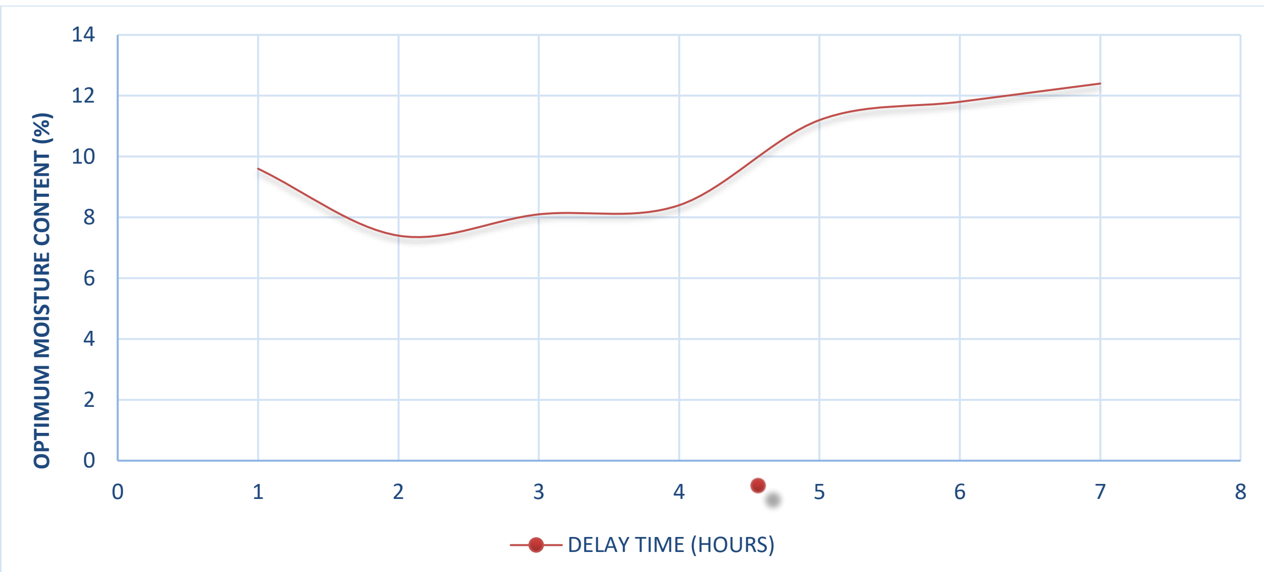

Figure 4: Optimum Moisture Content Behaviour

VI. UNCONFINED COMPRESSIVE STRENGTH

The 7-day UCS test results presented in figure 5 demonstrate a small improvement as compactive effort is increased. At 2 hours delay time, the highest in 7-day UCS value for the BSH energy level was 747KN/m2. These values fell short of the 1710KN/m2 threshold for stability defined by TRRL (1977). The UCS at 14 and 28 days differed from one another and from the 7-day curing period for BSH Compactive efforts, with values of 1139kN/m^2 and 2027 kN/m^2 at 2 hours delay, as shown in figure 5 below. In addition, figure 6 shows the variation of delay effect in percentage on the 7 days, 14 days and 28 days respectively. This suggests that soil stabilized with metakaolin has the capacity to gradually acquire strength over time, which implies that the pavement will become more stable as strength gradually increases.

Table 1 Unconfined compressive strength test results of the lateritic soil treated with 10% metakaolin

Delay Time	7 Days	14 Days	28 Days
0 Hours	346	719	1754

2 Hours	747	1139	2027
4 Hours	717	1019	1663
6 Hours	500	780	1270
8 Hours	355	580	1000
10 Hours	317	520	850
24 Hours	300	490	750

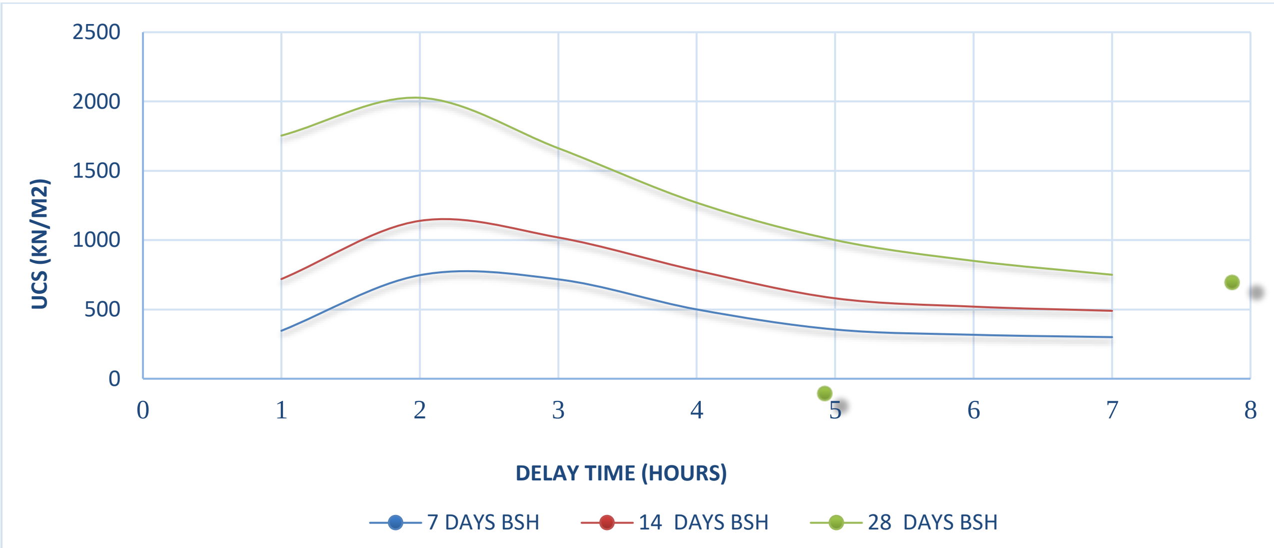

Figure 5: Unconfined Compression Strength B.S Heavy

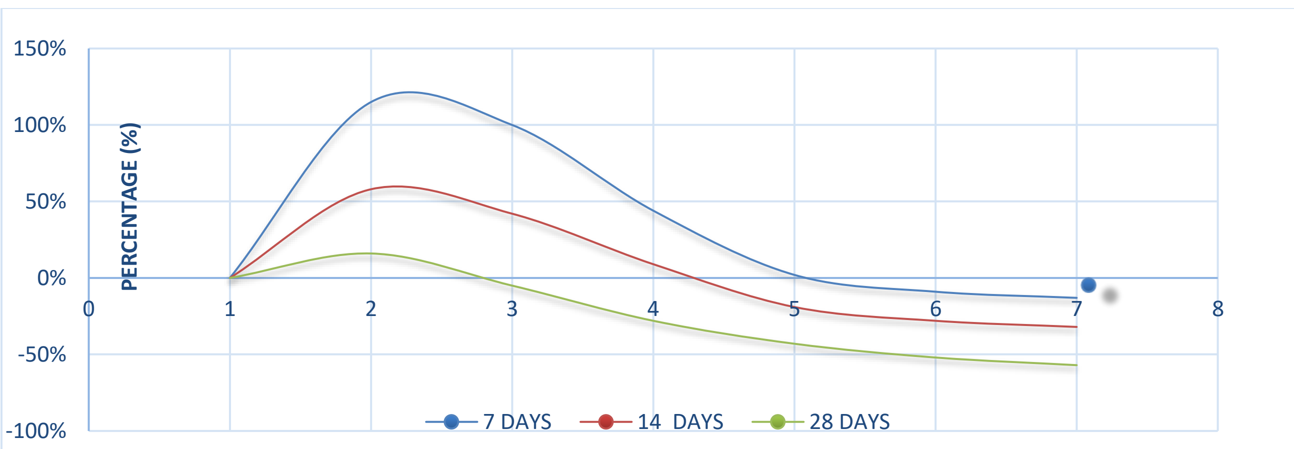

Figure 3: Variation of Delay Effect

VII. CALIFORNIA BEARING RATIO TEST

The CBR test was carried out on both natural soil and treated soil with a predetermined percentage of metakaolin. The CBR value was computed based on the test results, this is accomplished by expressing the corrected values of plunger forces for a particular penetration as a percentage of a standard force. To compare the loads that induced the same penetration on the specimens, the 2.5mm and 5.0mm penetration caused by 13.24 kN and 19.96 kN loads were chosen. The peak CBR value of 43% and 39% Un-soaked and soaked were recorded at 2 hours delays time. However, at 4-24 hours delay a decrease in value of CBR for the BSH Compactive effort was observed.

Table 4: California bearing ratio test results of lateritic soil stabilized with 10% of metakaolin

Delay time (hours)	Un-soaked (%)	Soaked (%)
0	38	34
2	43	39
4	39	35
6	33	31
8	28	26
10	24	23
24	22	20

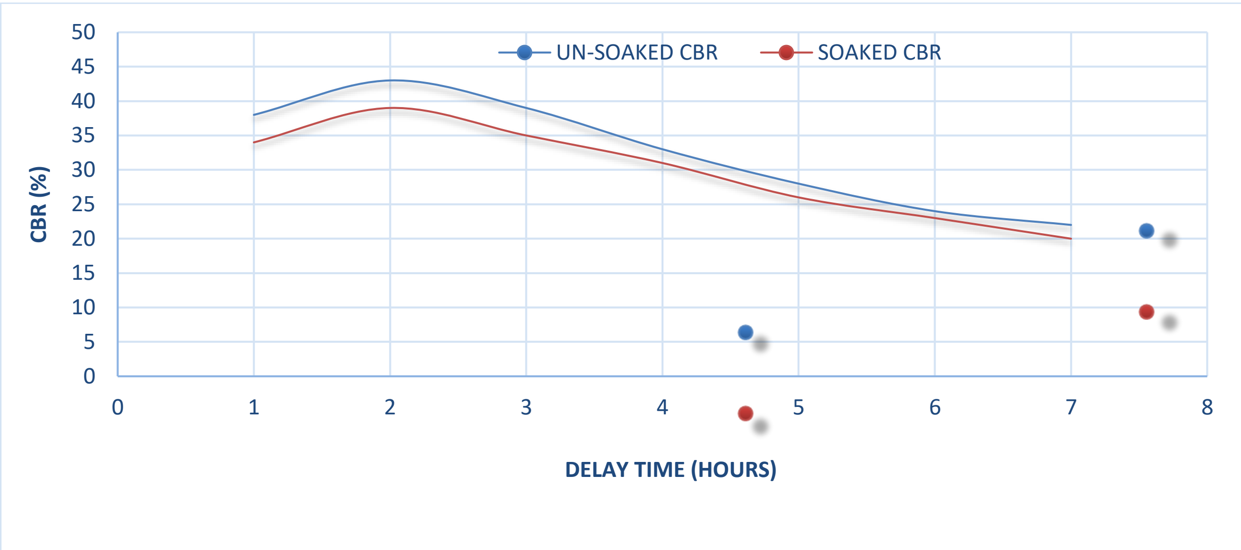

Figure 7: California bearing ratio (CBR) result

VIII. CONCLUSION AND RECOMMENDATION

10.1 Conclusion

Lateritic soil qualities were examined in the laboratory and appraised in terms of their potential as subgrade and base course materials in road building. The metakaolin stabilised lateritic soil's compaction and strength characteristics deteriorated as the compaction delay increased; metakaolin enhanced the geotechnical qualities of the lateritic soil. The highest strength was obtained after 2 hours of delay time.

10.2 Recommendation

It is advised against allowing compaction delays of more than two hours in this kind of stabilisation. To determine if this material will attain the UCS value for the sub-base and base course required by the Nigerian General Specification for Road and Bridges Vol II, more study on it is advised by adjusting the delay duration to less than 2 hours (1997) The results of this study are suggested to be helpful in reducing the delay in compaction for soil treated with metakolin that is reddish brown lateritic.

REFERENCES

[1] AASHTO American Association of State Highway and Transportation Officials (AASHTO). Standard Specification for Transportation Materials and Methods of Sampling and Testing (14th Edition), USA: Washington DC.

[2] Akoto, B. K. A. (1987): "Laboratory Investigation on the use of Pulverised Fuel Ash in Road Construction". Proc. of 9th Reg. Conf. for Africa on SM & FE, Lagos, 1, pp. 529534.

[3] Alabadan B. A., Njoku, C. F. and Yusuf, M. O. (2006). The Potential of Groundnut Shell Ash as Concrete Admixture. Agricultural Engineering

International: the CIGR E journal. Manuscript BC 05012, Vol. VIII.

[4] Alhassan, M., Mesaiyete, E. and A. M. Mustapha. (2012). Clay Mineralogy of Lateritic Soils Derived from granite Basement-A case Study of Minna lateritic Soils. *Electronic Journal of Geotechnical Engineering, Oklahoma, USA, vol. 17(M)*, pp.1897–1903.

[5] ASTM C618-12, (2012). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, ASTM International, West Conshohocken, PA, 2012, www.astm.org ASTM (1992).

[6] Braja, C. B. (2006). Stabilization of soil of Indian origin. International Journal of Scientific and Research Publications, 3 (3) pp 350.

[7] BS 1377 (1990): Method of Testing Soils for Engineering Purposes. British Standard Institute, London, United Kingdom

[8] Hill, I. G.; Worden, R. H. and Meighan, I. G. (2000). "Geotechnical Evolution of Palaeolaterite: the Interbasaltic Formation, Northern Ireland" Chemical Geology, 166(1-2), pp 65. Doi: 10.1016/S0009-2541(99)00179-5, Retrieved April , 2017.

[9] Ola S. A. (1974): Stabilization of Nigerian Laterite Soils with Cement, Bitumen and Lime. Proceedings of the sixth Regional conference for Africa on Soil Mechanics Foundation Engineering. Durban, South Africa. 1: pp145 - 152.

[10] Oriola, F. and Moses, G. (2010). Groundnut Shell Ash Stabilization of Black Cotton Soil Electron.

[11] Osinubi, K. J. and Nwaiwu, C. M. O. (2006). Compaction delay effects on properties of lime-treated soil. Journal of Materials in Civil Engineering ASCE, Vol. 18, No. 2, 250-258

[12] Osinubi, K. J. and Nwaiwu, C. M. O. (2007). Hydraulic Conductivity of Compacted Lateritic Soil. Journal of Geotechnical and Geoenvinmental Engineering, ASCE, Vol. 131 (8, 1034-1041)

[13] Poon, C. S., Kou, S. C. and Lam, L. (2002). Pore size distribution of high performance metakaolin concrete. Journal of Wuhan University of Technology- Materials Science Edition, Vol.17, No.1, 42-46.

[14] Tardy, Y. (1997): Petrology of Laterites and Tropical Soils ISBN 90-5410-678-6. Retrieved November 7, 2016.

[15] TRRL (1977). A guide to the Structural Design of Bitumen Surfaced Roads in Tropical and Sub-tropical Countries, Transport and Road Research Laboratory, Road Note 31, H. M. S. O., London.

[16] Umar, S. Y., Elinwa, A. U. and Matawal, D. S. (2015). Hydraulic Conductivity of Compacted Lateritic Soil Partially Replaced with Metakaolin. Journal of Environment and Earth Science, Vol.5 No.4, 53-64.