Compaction Behaviour of Lateritic Soils Stabilized with Blends of Groundnut Shell Ash and Metakaolin

Ali Alhaji Abdu[1*] Ali Musa Kundiri[2] Suleiman Arafat Yero[3]
1.Department of Dam and Reservoir, Ministry of Water Resources Damaturu, Yobe State, Nigeria
2.Department of Civil and Water Resources Engineering, University of Maiduguri, Borno State, Nigeria
3.Department of Civil Engineering, Abubakar Tafawa Balewa University, Bauchi State, Nigeria

Abstract
The study investigates the potential of groundnut shell ash (GSA) - Metakaolin (MK) blend for stabilization of lateritic soil, with a view to improving the properties of lateritic soils for road construction. In flexible pavements lateritic soil are used as materials for sub-grade and sub-base construction. In some cases lateritic soils pose serious challenges when encountered as road construction materials due to the presence of clay. The soil was classified as A-2-6(0) and CL according to the American Association of State Highway and Transport Officials (AASHTO) and Unified Soil Classification System (USCS) Classifications. Chemical analysis revealed that the soil is lateritic soil due to the Silica - sesquioxide ratio which falls within the ranged 1.33 to 2.00 as defined by Bell (1993). The soil was stabilized with increment of 2-10% GSA and 5-25%MK by weight of the dry soil. The laboratory tests were carried out using three energy levels such as British Standard light (BSL), British Standard heavy (BSH) and West African Standard (WAS). California bearing ratio (CBR), Unconfined Compressive strength (UCS), and Compaction test were also carried out. The result obtained showed a decrease in plasticity index (PI), Liquid limit (LL), plastic limit (PL), and water absorption. There was an increase in Maximum dry density (MDD) with increase in GSA and MK contents in the mix proportions used. There was also improvement in the CBR which resulted to an optimum of 36%, 154% and 81% using BSL, BSH and WAS compactive effort respectively; which met the acceptable requirement for sub-grade, sub-base and base course of highly trafficked roads in Nigeria. The UCS values at 7 days cured of 402, 731 and 530kN/m^2 fell short of 1710kN/m^2 and 1034.25kN/m^2 evaluated in the criteria recommended by TRRL road Note: 31 and Nigerian General Specification for Road and Bridges. The durability of specimen met 80% resistant to loss in strength.
Keywords: Metakaolin, Subgrade, Sesquioxide, California bearing ratio, Unconfined compressive strength

1. Introduction

The concept of the application of chemical or mechanical treatment of soil increase its stability or / and improve its engineering properties commonly referred to as stabilization, which is a panacea utilize on the abundant and available resources of nature for road construction purposes. The over dependence on industrially manufactured additives such as cement, lime and bitumen have kept the cost of construction of stabilized road financially high (Oriola and Moses, 2010). Studies have shown that groundnut shell ash and metakaolin contain high silicon oxide which made it highly pozzolanic material (Alabadan et al., 2006 and Umar *et al.,* 2015). The application of the groundnut in some parts of human endeavour enhances sustainability of the environment and economic development, especially in developing countries (Nakoo, 1999).

In the same vein, metakaolin (MK) is a supplementary cementious material (SCM) that conforms to the American Society for Testing and Materials (ASTM) C618-12 Class N pozzolan specifications (2012). Metakaolin (MK) is unique in that, it is not a by-product of an industrial process; it is derived from a naturally occurring mineral and is manufactured specifically for cementing applications (Brooks and Johari, 2001). The chemical analysis of MK was carried out by Umar et al. (2015), are as follows: SiO_2 -53.7%, Al_2O_3 -34.2%, Fe_2O_3 -3.84%, CaO-0.513%. MK boosts the 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). MK combines with the calcium hydroxide to produce additional cementing compounds, which is responsible for holding the concrete together. Less calcium hydroxide and more cementing compounds means stronger concrete or soil (The concrete countertop institute, 2007).

In the third world countries, the most common and readily available material that can be used as partial replace for cement without economic implications that researchers cheaply found locally include Bagasse Ash, Blast Furnace Slag, Metakaolin, Bambaranut Shell Ash, Cattle Bone Powder Ash, Groundnut Shell Ash (GSA) and Rice Husk Ash (Alabadan et al., 2005; Osinubi et al., 2006; Mohammed, 2007; Oriola and Mosees, 2010; Iorliam et al., 2012; Maskell et al., 2015 and Umar et al., 2015). Additional agro waste material include Ashes from the burning of dried banana leaves, sugarcane, bamboo leaves, some timber species, sawdust and Periwinkle Shell Ash (PSA), (Mahmoud et al., 2012).

However, this study investigated the possibility of using agricultural and industrial waste such as groundnut shell ash and metakaolin that could considerably reduce the cost of construction and eliminate environmental hazards that is likely to result from such wastes.

2. Materials and Method

The soil use in this study is a natural occurring laterite which is reddish brown in colour, with the soil sample being obtained from Potiskum local government area of Yobe State, Nigeria (latitude 11^0 $50^'$ N and longitude 13^0 $09^'$E); at a depth of 1 - 1.5m below the ground level using the method of disturbed sampling. The particle size distribution test and stabilization of the soil were conducted in accordance with the specifications outlined in BS: 1377 (1990) and BS: 1924 (1990). Results of the physical properties and oxide composition are summarized in Tables 1 and 2. Chemical analysis was carried out at Abubakar Tafawa Balewa University (ATBU), Bauchi; using Atomic Absorption Spectrophotometer (AAS) to determine the oxide composition of the soil, GSA and MK as shown in Table 2. The soil was classified as A-2-6(0) and CL using the American Association of State Highway and Transportation officials (AASHTO, 1986) soil classification system and unified soil classification system(USCS), (ASTM, 1992) respectively. The liquid limit, plastic limit and plasticity index of the natural soil were observed to be 28, 17 and 11%. Kaolin was obtain from Alkaleri local government area of Bauchi state, and was calcined to a temperature of about 500 to $800C^0$ in a laboratory at ATBU to obtained the Metakaolin (MK) for this study. The groundnut shell ash used for this research was sourced locally and burned to ashes in an open air from a farm at Potiskum local government area of Yobe state. The resulting ash was carefully sieved through 0.075mm sieve aperture to remove any unwanted materials.

Table 1: Physical properties of the Natural soil

Natural moisture content (%)	12.5
Liquid limit (%)	28
Plastic limit (%)	17
Plasticity index (%)	11
Linear shrinkage (%)	5
Percentage passing BS No. 200 sieve	3.23
Gravel, (>4.76mm), (%)	53.2
Sand, (0.075-4.7mm), (%)	46.15
Fines, (<0.075mm), (%)	0.65
Free swell (%)	10
Specific gravity	3.2
AASHTO classification	A-2-6
USCS classification	CL
Group Index	(0)
Water absorption	3.23
Colour	Reddish Brown

Table 2: Oxide composition of the soil, GSA and MK

Property	soil (%)	GSA (%)	MK (%)
Silicon (SiO_2)	39.64	26.46	43.94
Aluminium (Al_2O_3)	23.28	28.39	74.78
Iron (Fe_2O_3)	6.15	0.86	0.43
Calcium (CaO)	1.54	21.55	0.84
Magnesium (MgO)	8.46	61.35	1.82
Sodium (Na_2O)	56.62	47.18	4.04
Potassium (K_2O)	12.05	65.05	24.09

2.1 Compaction Tests

The compaction tests were carried out using the three different compactive efforts of: British standard light compaction (BSL), British standard heavy (BSH) and West African standard (WAS) compaction. For the B.S light, three layers, each layer received 27 blows using 2.5kg rammer with height of fall of 300mm. In the B.S heavy compaction method, the same procedure was followed, but 4.5kg rammer with a height of fall of 450mm and using 5 layers. For the West African standard compaction, the same procedure was followed as in the case of BSH; but using 10 blows. The stabilized soil compaction was carried out using the same compactive efforts of BSL, BSH and WAS. The blends of GSA and MK were added to the samples before compaction, and the moisture content for every water increment was determined. Curves were plotted for the moisture-density relationship using the dry densities and compaction moisture contents.

2.2 Strength test
The batches of soil with admixtures were prepared by mixing with the desired proportion of portable water obtained from the moisture-density relationship. The mixes consisted of blends of 2-10%GSA and 5-25%MK by the dry weight of soil. The CBR and UCS test specimen were compacted at the energy levels of BSL, BSH and WAS compaction, and the sample specimens were cured for 7, 14 and 28days in case of UCS.

2.3Durability test
The durability assessment of the soil stabilized specimens was carried out by immersion in water to measure the resistance to loss in strength rather than wet-dry and freeze thaw test highlighted in ASTM [Annual 1992], that are not very effective under the tropical condition. The resistances to loss in strength were determined as a ratio of the 7 days cellophane - cured specimens, unsealed, and later immersed in water for another 7days to that of the 14 days UCS value of cellophane-cured specimens.

3. Result and Discussion
3.1 Compaction Characteristic
The natural soil when compacted at the energy of BSL compaction yielded the highest MDD value of 1.79 Mg/m^3 which corresponded to the OMC value of 13%. On the other hand, the soil compacted at the energy of BSH gave an MDD value of 1.94 Mg/m^3 with a corresponding OMC value of 10.8%, while the WAS compaction gave an MDD value of 1.84 Mg/m^3 with a corresponding OMC value of 10%.

Fig.1 shows that an increase in MDD brought about with an increase in the compactive effort, with corresponding decrease in OMC. As the percentages of the GSA and MK contents increase for the three energy levels of BSL, BSH and WAS, the magnitude of the MDDs also follow suits. This indicated that an increase in the dry density of the soils is a function of compaction energy. This assertion agrees with the previous researches by (Nwaiwu et al., 2004; Osinubi and Nwaiwu, 2005; Osinubi et al., 2006; Mohammed, 2007; Umar, 2014).

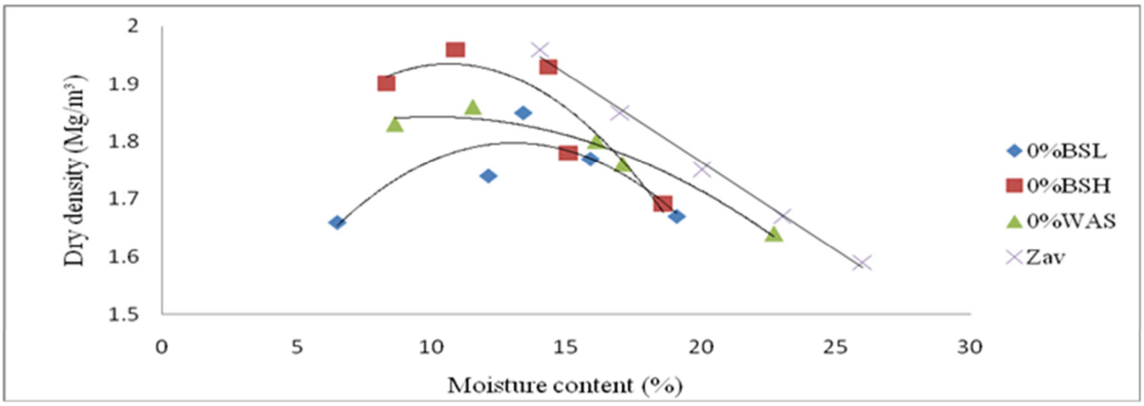

Fig. 1: Moisture – density relationship for the natural soil.

3.2 Effect of GSA and MK on Maximum Dry Density
The increase in MDD was attributed to the formation of new compounds, increase in surface area of particles at higher dosage of GSA and MK blends, as well as improved workability of the soil due to the increase in the percentage of CaO and the desiccating property of MK in the mixture. This is due to the fact that soil mixtures have difference in specific gravity than the original soil. This trend agrees with earlier research by (Osinubi, 1999; Stephen, 2005; Moses, 2008;) The fine particles of the GSA and MK influenced the compatibility and soil interaction, this resulting in the cementitious products with gained in strength. Figures 2-4 show the variation of MDD with blend of GSA- MK content for the three compactive efforts. For BSL compactive effort in Fig. 2, 4 and 10% GSA gave the optimal blends, while 2 and 8% were associated with the minimum and maximum values of MDD attained respectively. In the same vein, BSH and WAS compactive efforts presented in Fig. 3 and 4 gave optimal blends at 8 and 2% respectively.

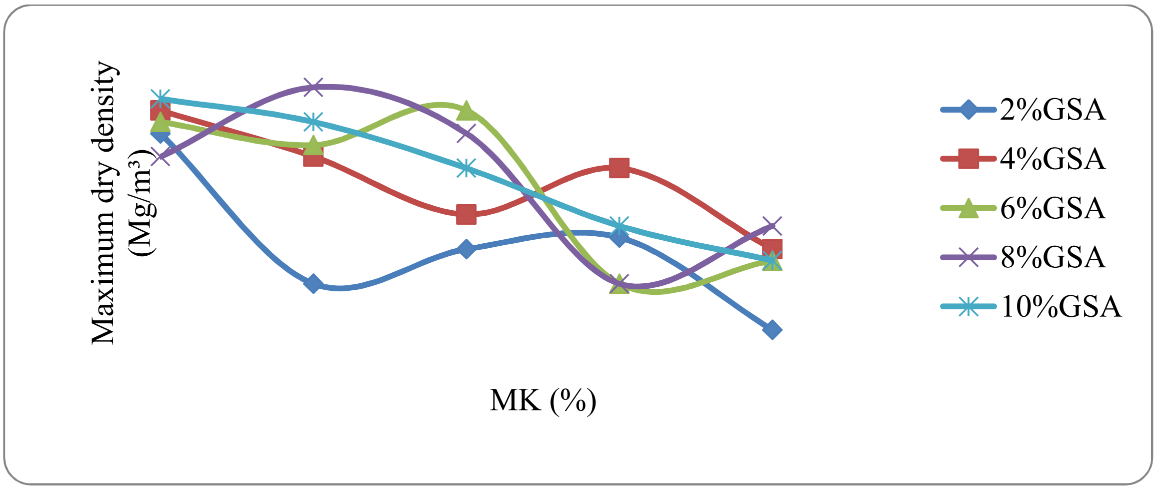

Fig. 2: Variation of MDD with blend of GSA-MK treated soil using BSL compactive effort

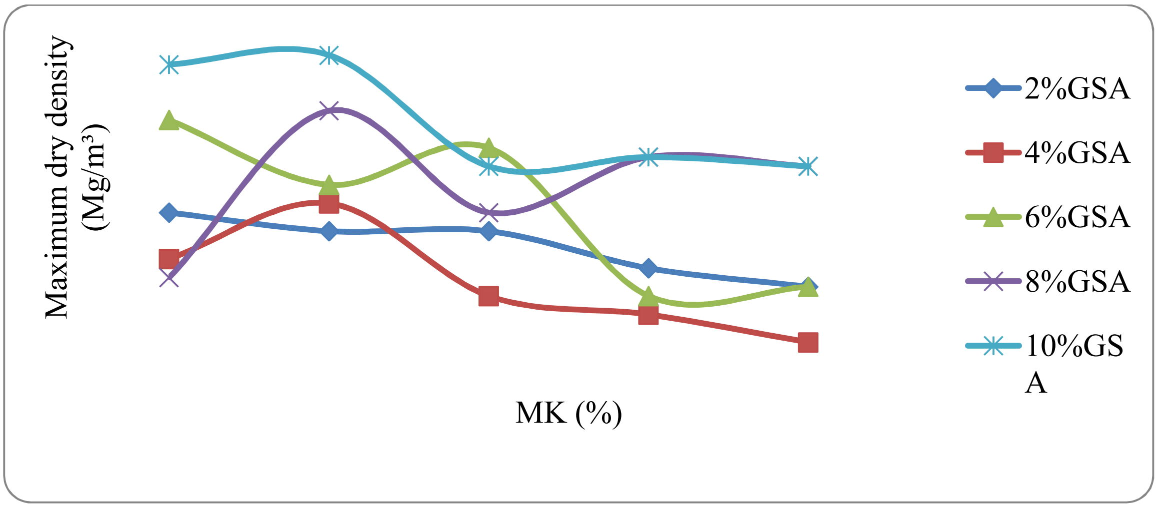

Fig. 3: Variation of MDD with blend of GSA-MK treated soil using BSH compactive effort

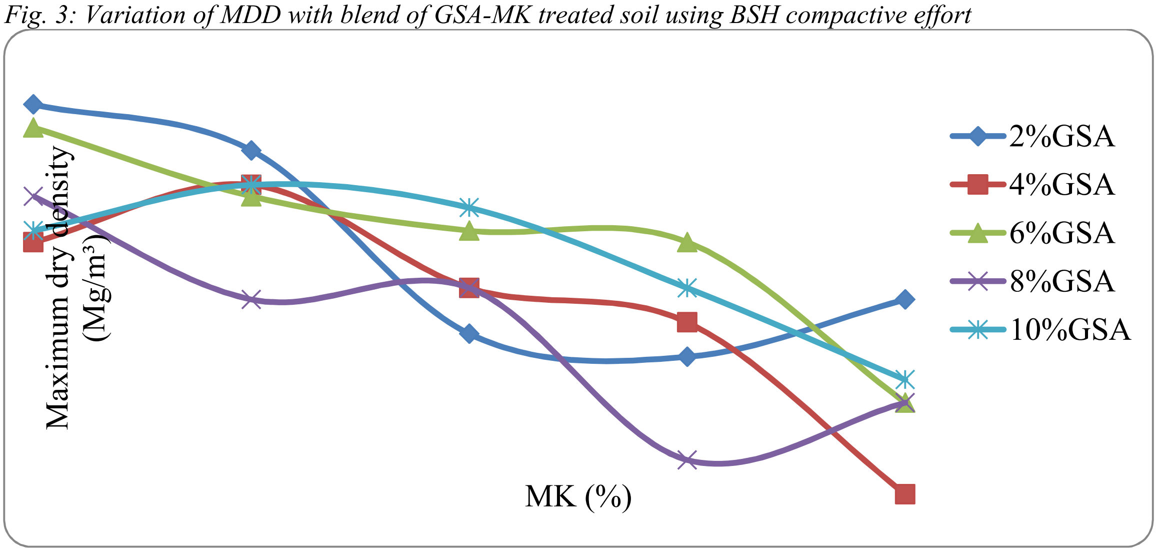

Fig. 4: Variation of MDD with blend of GSA-MK treated soil using WAS compactive effort

3.3 Effect of GSA and MK on Optimum Moisture content

There was an initial increase in OMC with increase in blends of GSA and MK content for the three energy levels. The initial increment could be as a result of increasing demand for water by various cations and the clay mineral particles to undergo hydration and pozzolanic reaction (Osinubi and Stephen, 2006). The subsequent decrease might be due to the cation exchange reaction that caused flocculation of the particles. Fig. 5 – 7 show the variation of OMC with the different blends of GSA and MK contents. For the BSL compactive effort, 10% GSA gave the optimal blend. The BSH and WAS compactive efforts had 2 and 6% GSA as the optimum blends.

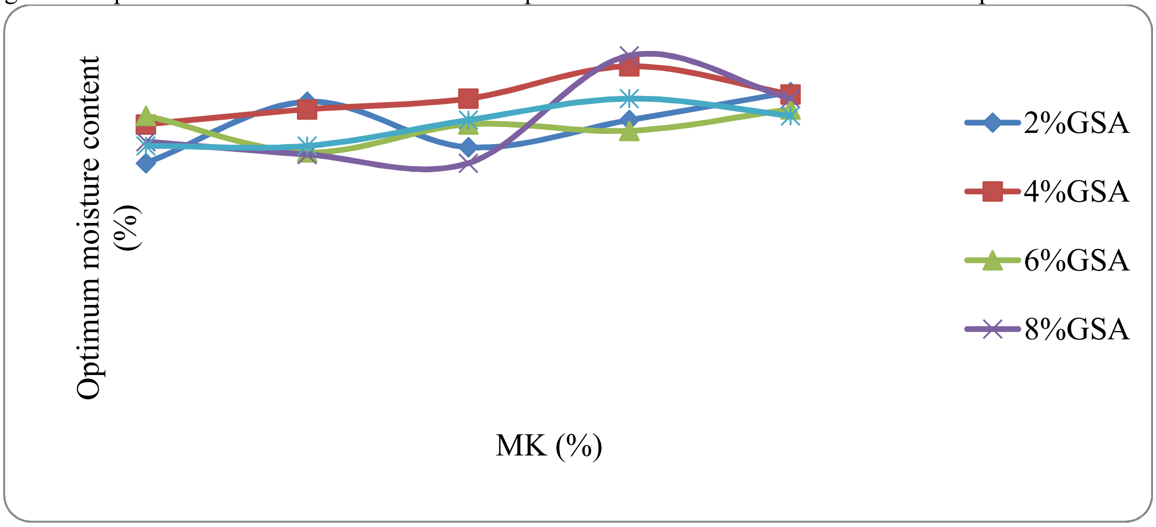

Fig. 5: Variation of OMC with blend of GSA-MK treated soil using BSL compactive effort

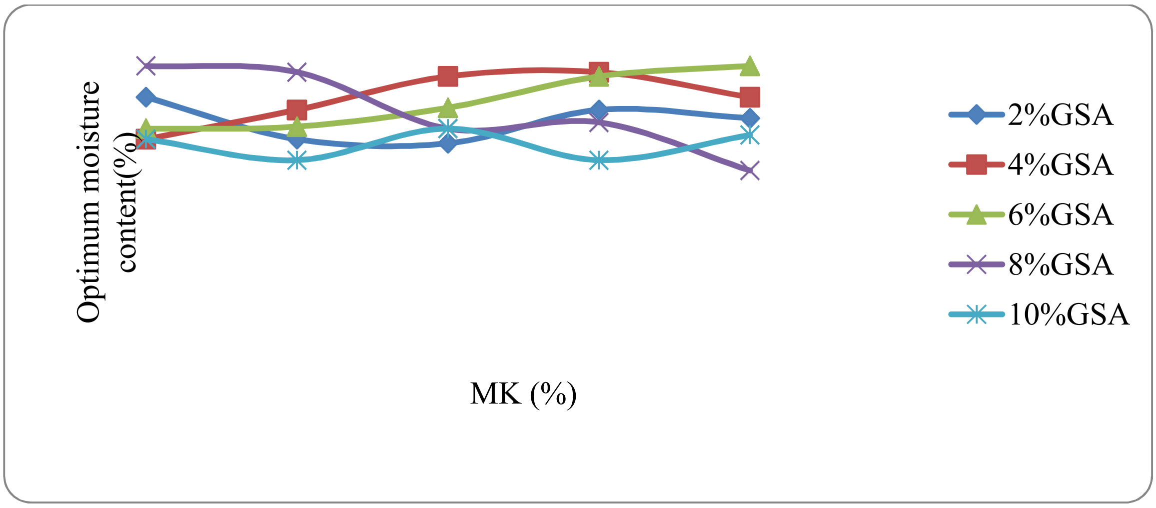

Fig. 6: Variation of OMC with blend of GSA-MK treated soil using BSH compactive effort

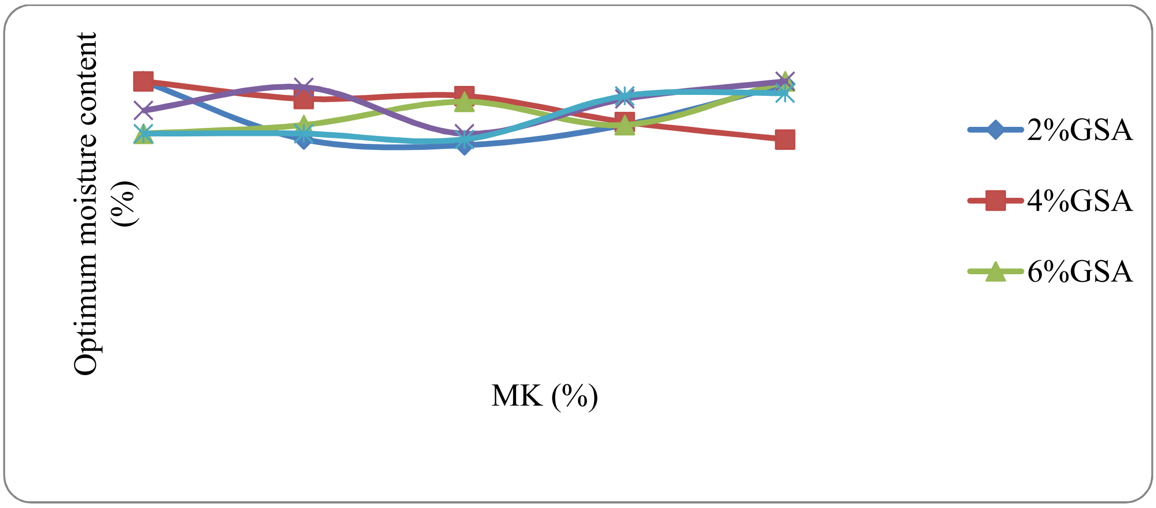

Fig. 7: Variation of OMC with blend of GSA-MK treated soil using WAS compactive effort

4. Strength Characteristic

4.1 Unconfined compressive strength

The 7days UCS test result shown in fig. 8-16, indicate slight improvement with increase in compactive effort. The peak 7days UCS values for the BSL, BSH and WAS energy levels were 402, 731 and 530KN/m^2. These values failed short of 1710KN/m^2 specified by TRRL (1977) as criterion for stabilization using OPC as in Fig. 8-10. The UCS at 14days showed differences in values from one another and from that of the 7days curing period for BSL, BSH and WAS compactive efforts, these values were 699kN/m^2 at 4%GSA and 20%MK, 1213kN/m^2 obtained at 8%GSA and 5%MK and 958kN/m^2 at 6%GSA and 5%MK as presented in Fig. 11-13. This indicates that GSA – MK mixture has long time strength improving capability, which implies that the progressive increase in strength will enhance the stability of the pavement. The peak value at 28days curing is 1161, 1400 and 1210kN/m2 using BSL, BSH and WAS compactive efforts respectively, as shown in Fig. 14-16. The development of high UCS values at the 28-days curing period is attributed to the effect of GSA- MK which promote the production of alkaline compounds that increases the pH value of the soil and promote the self-hardening characteristics of the admixture.

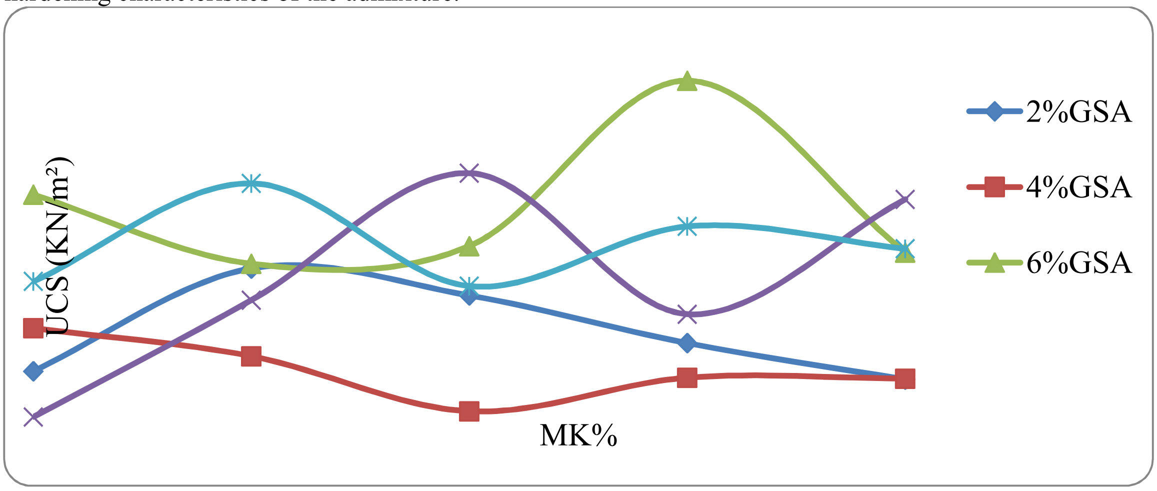

Fig. 8: Variation of UCS for 7days cured with blend of GSA-MK mixtures using BSL compactive effort.

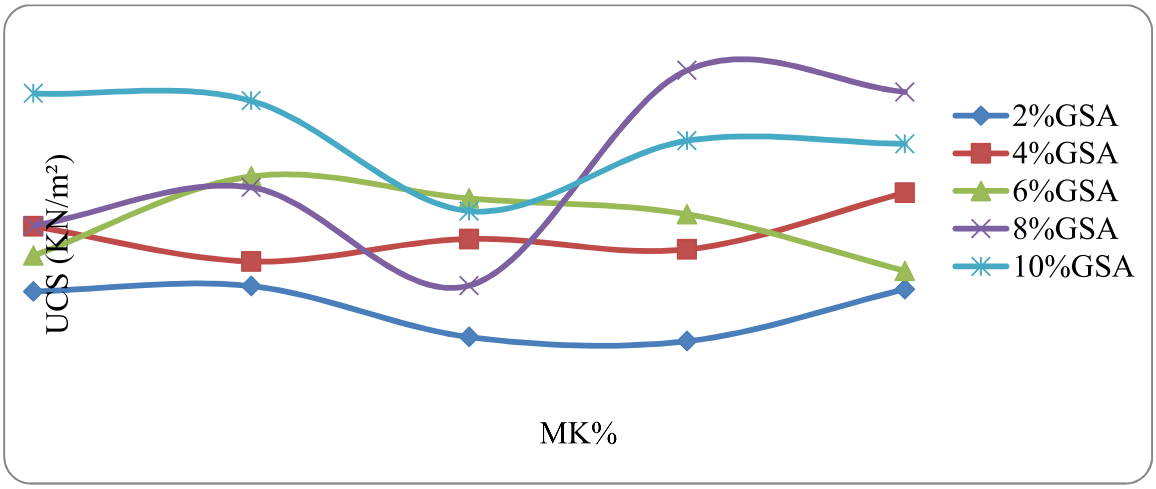

Fig. 9: Variation of UCS for 7days cured withblend of GSA-MK mixtures using BSH compactive effort.

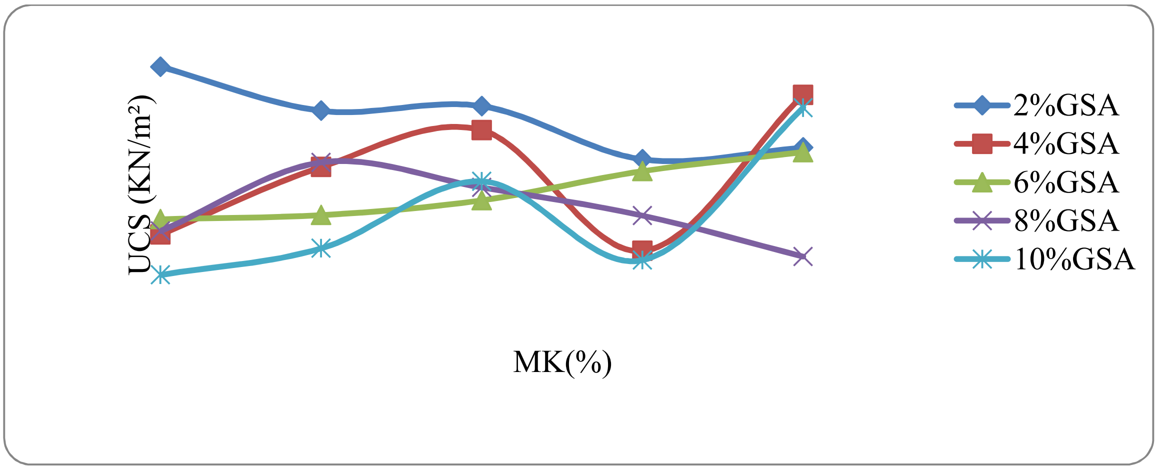

Fig. 10: Variation of UCS for 7days cured withblend of GSA-MK mixtures using WAS compactive effort.

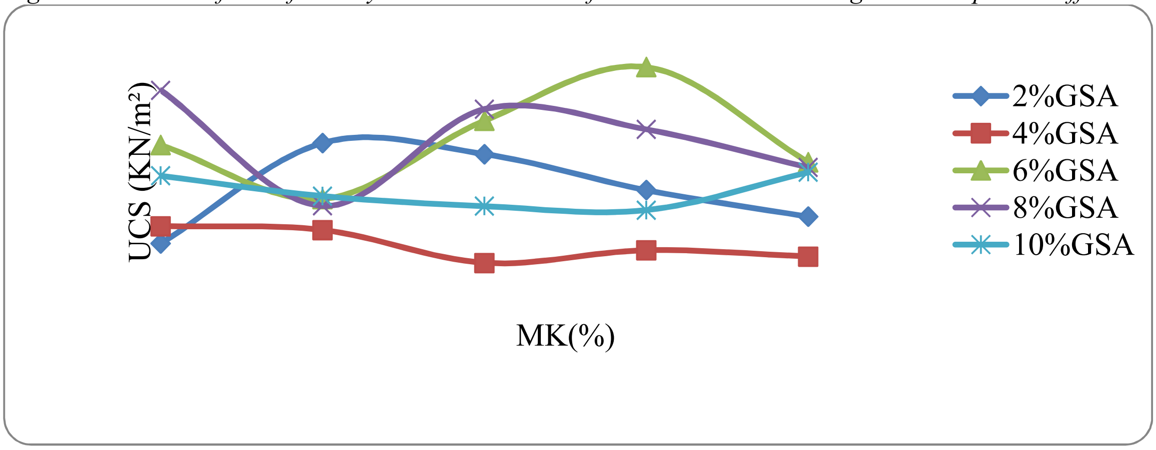

Fig. 11: Variation of UCS for 14days cured with blend of GSA-MK mixtures using BSL compactive effort.

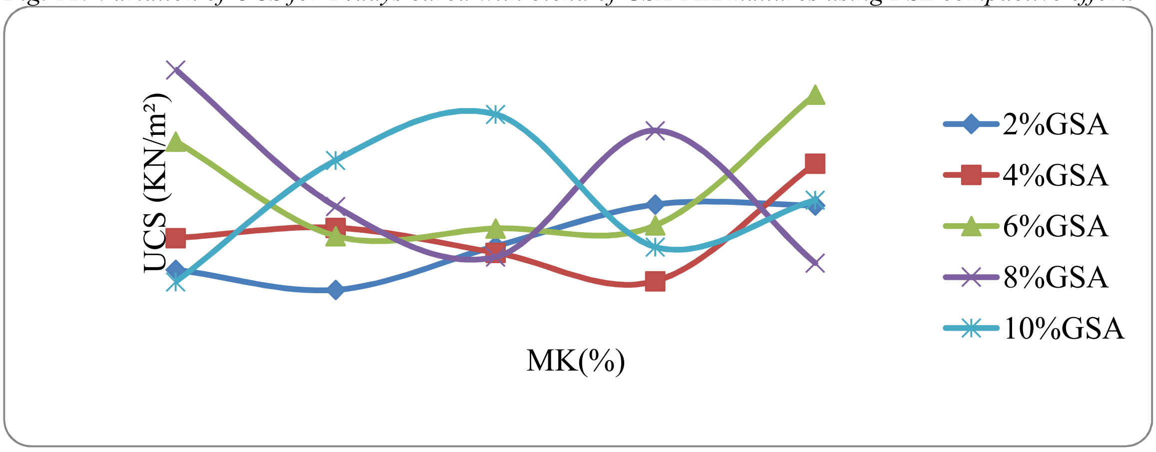

Fig. 12: Variation of UCS for 14days cured with blend of GSA-MK mixtures using BSH compactive effort.

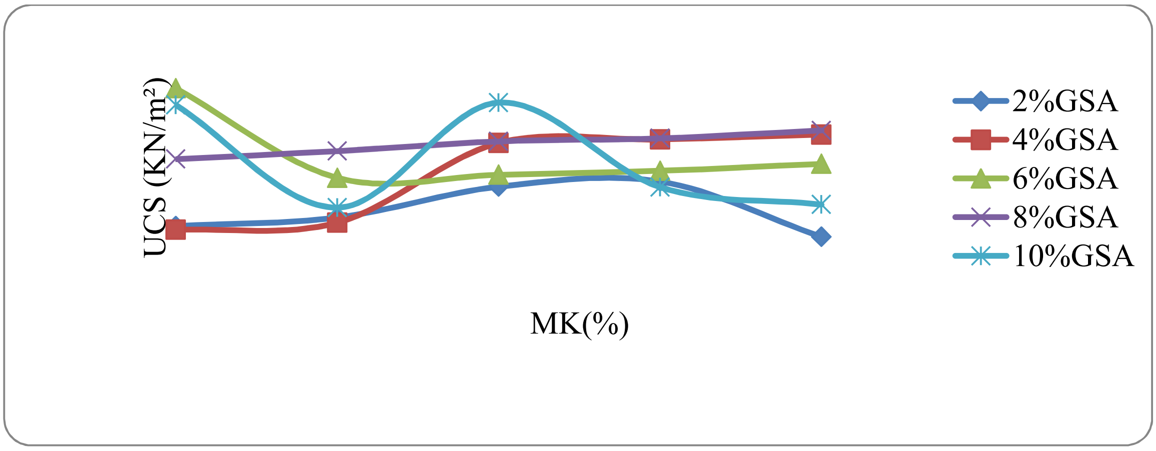

Fig. 13: Variation of UCS for 14days cured with blend of GSA-MK mixtures using WAS compactive effort.

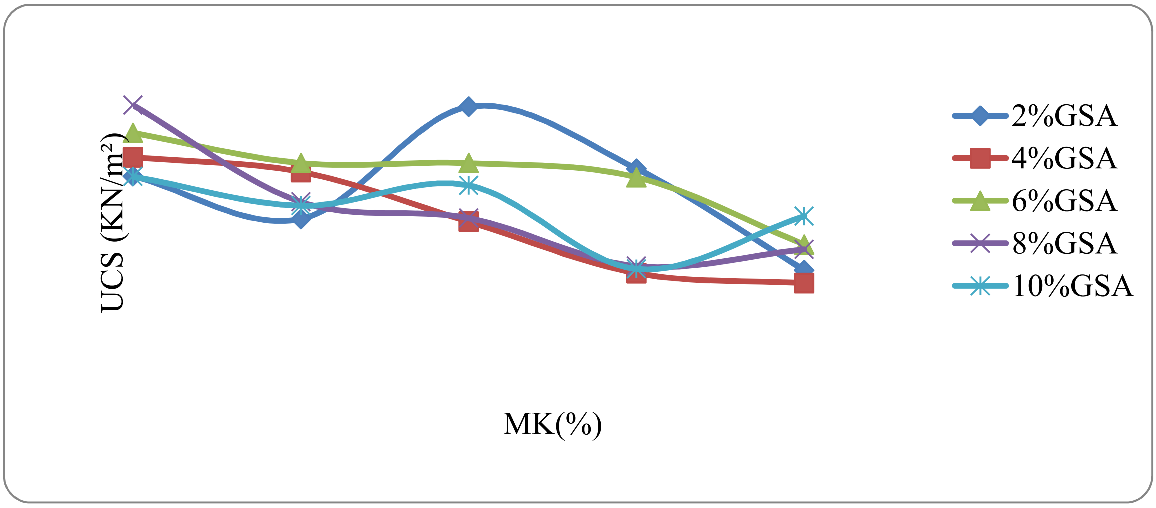

Fig. 14: Variation of UCS for 28days cured with blend of GSA-MK mixtures using BSL compactive effort.

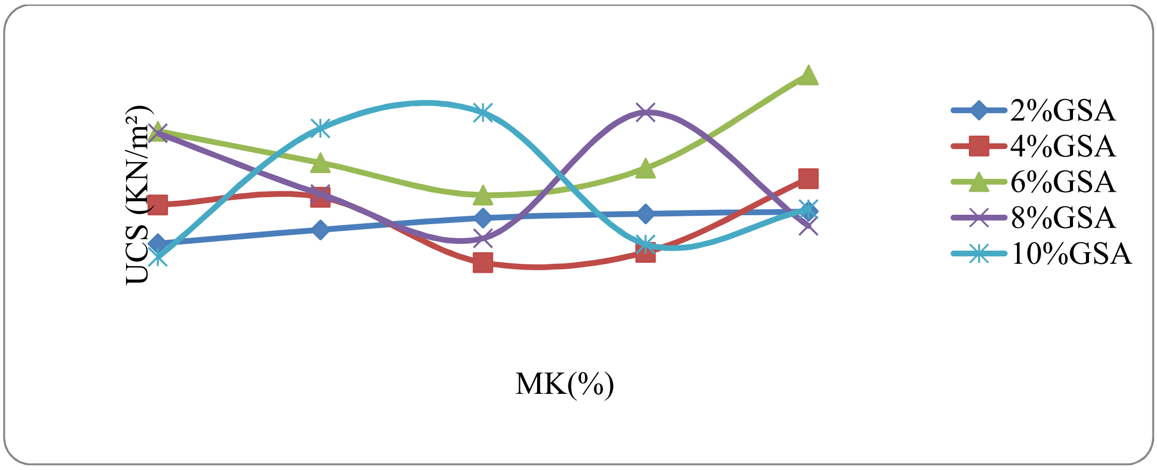

Fig. 15: Variation of UCS for 28days cured with blend of GSA-MK mixtures using BSH compactive effort.

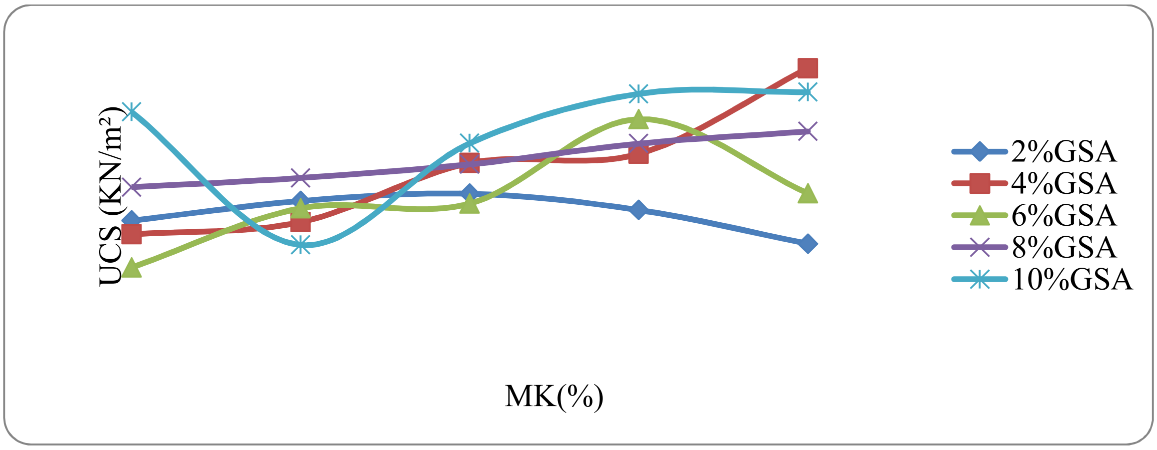

Fig. 16: Variation of UCS for 28days cured with blend of GSA-MK mixtures using WAS compactive effort.

4.2 California bearing ratio

The California bearing ratio (CBR) value, of the stabilized soil is an important parameter in gauging the suitability of the stabilized soils. This gives an indication of the strength and bearing capacity of the soil; which will assist the designer in recommending or rejecting the soil as a base or sub-base material. Fig. 17 - 19 show the variation of the un-soaked CBR with different blends of GSA and MK contents using the BSL, BSH and WAS compactive efforts. A peak value of 36% CBR was observed at 6/5% GSA and MK mixture for BSL, the value of 154% CBR was obtained at 10/20% GSA and MK content for BSH, while 81% CBR was obtained at 10/5% GSA and MK content for WAS compactive effort. These values have met the minimum requirement specified for CBR values of 40, 80 and 100% treated soil for sub-base and base material for highly traffic roads. This has been recommended by the Nigerian General Specification for Roads and Bridges, (1997) in an earlier research by (Osinubi, 1999).

In Fig. 17, 2, 4, 6 and 10% GSA showed erratic trends, but 8% GSA gave an almost linear relationship. Figure 18 had 2, 8, and 10% GSA which showed somewhat constant relationship between 10 – 20% MK. Decreasing trend were depicted by 4 and 6% GSA. In Fig. 19, decreasing trends were observed for 6 and 10% GSA while 2, 4 and 8% GSA presented erratic trends.

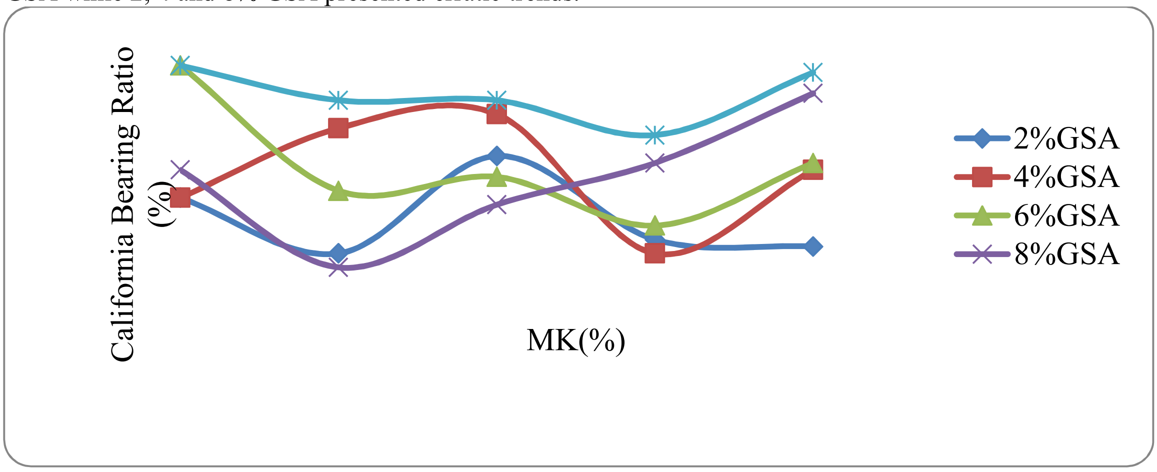

Fig. 17: variation of unsoaked CBR with blend of GSA-MK mixtures using BSL compactive effort

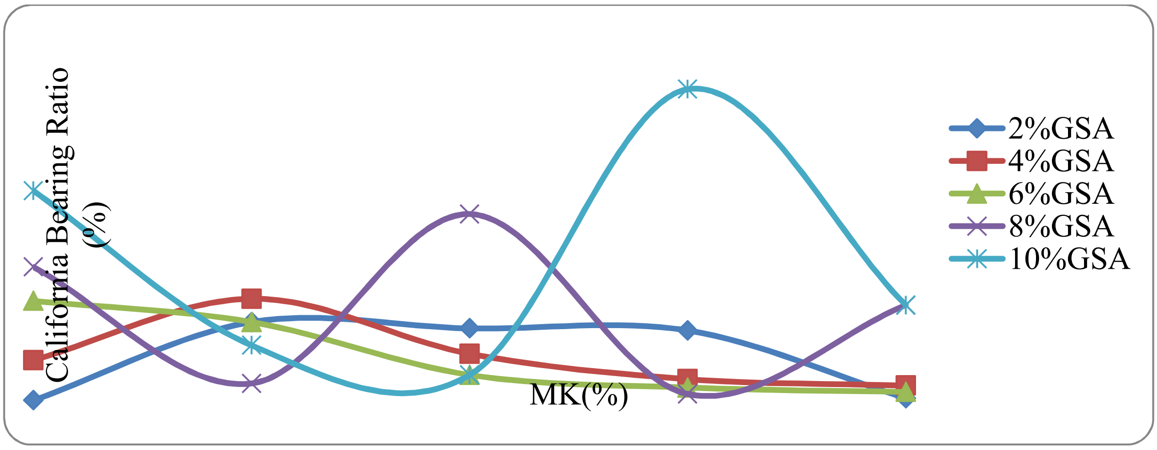

Fig. 18: Variation of unsoaked CBR with blend of GSA-MK mixtures using BSH compactive effort.

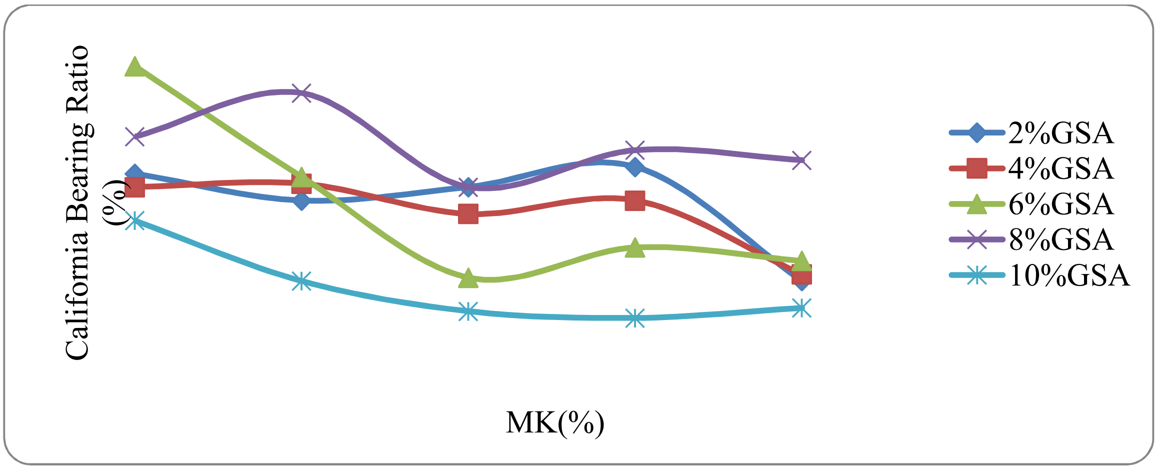

Fig. 19: Variation of unsoaked CBR with blend of GSA-MK mixtures using WAS compactive effort.

4.3 Durability

The durability of the treated specimens was carried out by immersing in water to determined the resistance to loss in strength rather than the wet-dry and freeze tests highlighted in ASTM (1992), which is not very effective under tropical conditions (Osinubi, 1998). The resistance to loss in strength was determined as a ratio of the unconfined compressive strength (UCS) of specimens cured for 7 days dewaxed top and bottom, and later immersed in water for another 7 days to that of UCS of specimens wax-cured for 14 days.

The durability of the specimen shows the loss in strength of 89.3%, 94% and 94.9% with BSL, BSH and WAS compaction energies respectively. The value recorded is more than the acceptable conventional 80% accepted as minimum resistance to loss of strength by (Ola, 1974).

5. Conclusion

The properties of lateritic soil were determined in the laboratory and evaluated on the basis of its potentials as sub grade and base course materials in road construction. The soil used for the study was obtained from Potiskum Local Government area of Yobe state and classified as A-2-6 (0) and CL based on the AASHTO (1986) classification and unified soil classification systems respectively. The silica sesquioxide ratio showed that the soil is lateritic in nature.

The geotechnical properties of the treated soil such as CBR and UCS were greatly improved by the additing blends of GSA- MK to the soil. The results clearly show that the energy level of BSH yielded higher CBR values of 154% at 10% GSA and 20% MK, which could be use as sub-base and base course materials based on the specification in the Nigerian General Specification for road and bridges (1997). It was also observed that the UCS value for 7 days cured sample was 731kN/m^2 at 8% GSA and 20% MK, and did not meet the criteria recommended for road sub-base (Ingles and Metcalf, 1972). The durability assessment met the acceptable requirement of 80% loss in strength.

References

Alabadan, B. A., Olutoye, M. A., Abolarin, M. S. and Zakariya, M. (2005). Partial Replacement of Ordinary Portland Cement (OPC) with Bambaranut Shell Ash (BGSA) in Concrete. *Leonardo Electronic Journal of Practices and Technologies. Issue **6**, 43,*

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 Ejournal. Manuscript BC 05012, Vol. **VIII.***

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 AASHTO, 1986.

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). Annual Book of Standards, Vol. **04**.08, American Society for Testing and Materials, Philadelphia.

Bell, F.G. (1993). Engineering Geology, Blackwell Scientific Publications, Oxford, 84-86.

Brooks, J. J. and Johari, M. A. M. (2001). Effect of Metakaolin on Creep and Shrinkage of Concrete Cement and Concrete Composites, Vol. **23**(6): 495-502.

B. S. 1377 (1990). Method of Testing Soil for Civil Engineering Purposes. British Standards Institute London.

B. S. 1924 (1990). Methods of Testing for Stabilized Soils. British Standard Institute London.

Federal Ministry of Works and Housing (FMWH). General Specification (Roads and Bridges) Revised Edition (Volume **II**), Nigeria. Abuja Federal Ministry of Works, 1997.

Ingles, O.G and Metcalf, J. B. (1972). Soil stabilization principles and practice. Burtter worths, Sydney, 103-144.

Iorliam, A.Y., Obam, S. O. and Owinizi, S. A. (2012). Improvement of Black Cotton Soil With Cattle bone Powder. *Am. J. Sci. Ind. Res., Vol. 3(3): 175-180.*

Mahmoud, H., Belel, Z. A. and Nwakaire, C. (2012). Groundnut Shell Ash as a Partial Replacement of Cement in Sandcrete Blocks Production. *International Journal of Development and Sustainability. Vol. **1**(3): 1026-1032.*

Maskell, D., Heath, A. and Walker, P. (2015). Use of Metakaolin with Stabilized Extruded Earth Masonry Units. *Construction and Building Materials, Vol. **78**(1): 172.*

Mindess, S., Young, F. J. and Darwin, D. (2003). Concrete, 2nd ed., Upper Saddle River: Prentice Hall.

Mohammed, A. M. (2007). Influence of Compactive Effort on Bagasse Ash with Cement Treated Lateritic Soil, Leonardo. *Elect. J. Prac. Tech., Vol. **6**(10): 79-92*

Moses, G. (2008). Stabilization of black cotton soil with ordinary Portland cement Using Bagasse ash as admixture. *IRJI Journal of Reseach in Engrg. Vol. **5** No. 3, 107-115*.

Nwaiwu, C. M. O., Alkali, I. B. K. and Ahmed, U. A. (2004). Properties of ironstone lateritic gravels in relation to gravel road pavement construction.*Geotechnical and Geological Engineering .Vol. **24**, 283-298.*

Nakoo, Y. (1999). Rice: Post Harvest Technology, ACE Corporation, Tokyo, 431.

Ola, S. A. (1974). Need for estimated cement requirement for stabilizing lateritic soil. *J. Transport Div., ASCE, Vol. **17**, No 8, 379-388.*

Oriola, F. and Moses, G. (2010). Groundnut Shell Ash Stabilization of Black Cotton Soil *Electron. J. Geotech. Eng., Vol. 15, 415-428.*

Osinubi, K. J. and Nwaiwu, C. M. O. (2005). Hydraulic Conductivity of Compacted Lateritic Soil. *Journal of Geotechnical and Geoenvinmental Engineering, ASCE, Vol. **131** (8, 1034-1041)*

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*

Osinubi, K. J., Eberemu, A.O. and Amadi, A. A. (2006). Compacted Lateritic Soil Treated with Blast Furnace Slag as Hydraulic Barriers in Waste Containment Systems. *International Conference on Infrastructure Development and the Environment (ICIDEN 2006), Abuja Nigeria.*

Osinubi, K. J. and Stephen, T. A. (2006). Effect of curing period on bagasse ash stabilized black cotton soil. Book of Proc. Bi-monthly Meeting/ Workshop, *Material Society of Nigeria., Zaria. 1-8.*

Osinubi, K. J. (1998). Influence of compactive efforts and compaction delays on lime- treated Soil, *Journal of Transportation Engineering, ASCE, Vol. **124** (2), 149-155.*

Osinubi, K. J. (1999). Evaluation of admixture stabilization of Nigerian black cotton soil. *Nigerian Society of Engineers Technical Transactions, Vol **34**, No 3, 88-96*.

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.*

Stephen, A. T. (2005). Stabilization Potential of Bagasse Ash on Black cotton Soil. *Unpublished M.Sc. Thesis, Department of Civil Engineering. Ahmadu Bello University, Zaria.*

The Concrete Countertop Institute, (2007). Available @ www.ConcreteCountertopInstitute.com

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.

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.*

Umar, S. Y. (2014), Effects of Additives on Compaction Characteristics of Lateritic Soil for Hydraulic Barrier System, *PHD (Geotechnical Engineering) Seminar* ***II.*** *Faculty of Engineering, Abubakar Tafawa Balewa Univasity Bauchi.*