[1.]Paul YOHANNA, [2.]Kazeem ISHOLA, [1.]Chen Manasseh AONDOVER,
[1.]Jiges Kamji FORTUNATUS, [1.]Fwangshak Gayus MIJE, [1.]Badamasi ABDULRAHMAN

A COMPARATIVE STUDY ON PROPERTIES OF LATERITIC SOIL TREATED WITH RICE HUSK ASH AND METAKAOLIN GEOPOLYMER

[1.] Department of Civil Engineering, University of Jos, Plateau State, NIGERIA
[2.] Department of Civil Engineering, Osun State University, Osogbo, Osun State, NIGERIA

Abstract: The impact of rice husk ash (RHA) and Metakaolin (MTK) geopolymer in improving lateritic soil for pavement application was investigated. RHA and MTK geopolymer each was applied to a soil sample in concentrations of 0, 5, 10, 15, and 20% by dry weight of soil. Particle size distribution, Atterberg limits and compaction test are among the tests performed. Using Microsoft Office Excel software, a one-way analysis of variance (ANOVA) was performed. Results obtained, noted that with an increase in geopolymers content, a decline in the proportion of fines in the soil was recorded. The liquid limit for both treated soil declined from its natural value of 50% to a minimum of 46 and 35% at 20% geopolymer, for RHA and MTK geopolymer in that order. The plastic limit of natural soil increased somewhat from 24.37% to highest values of 31.8 and 25.7% at 20% geopolymer for both RHA and MTK geopolymer treated soil respectively. In the case of plasticity index, values generally decreased with increasing geopolymer content for both treatments. Maximum dry density (MDD) increased at first, then later declined. MDD values of 1.64, 1.76, 1.75, 1.69, 1.62 Mg/m^3 and 1.62, 1.76, 1.7, 1.69, 1.71 Mg/m^3 were obtained at 0, 5, 10, 15, and 20% RHA and MTK geopolymer content, respectively. Optimum moisture content (OMC) initially declined and then increased with higher geopolymer content. Analysis of variance (ANOVA) demonstrates that RHA and MTK geopolymer has a substantial influence on the treated soil. According to the findings, a 20% RHA and MTK geopolymer blend improved the soil's geotechnical qualities and is recommended for geotechnical engineering applications such as sub-base material for rural roads.

Keywords: pavement application, geopolymer, rice husk ash (RHA), Metakaolin (MTK), ANOVA

INTRODUCTION

Lateritic soils that meet specific standards for usage as road construction materials are in high demand in emerging countries around the world, especially Nigeria and other Africa countries, due to the rising need for road infrastructure and massive population growth (Mir, 2015). There is pressure on geotechnical engineers to use weak soils like lateritic soil for the development of various infrastructures, but some lateritic soils are not readily appropriate for use as road construction material in their natural state (Francis and Vernantus 2013). As a result, there is a pressing need to increase efforts to improve locally available soils for use in road construction.

Lateritic soils are the product of tropical or subtropical weathering. They're also the most prevalent reddish, tropically pedogenic surface build-ups in Nigeria and other parts of the world, including Australia, Asia, and South America (Gidigasu 1976). Due to the poor state of this soil, technical soil stabilization was implemented to change its characteristics, such as shear strength and compressibility, and thus meet engineering standards for project sites (Venda Oliveira et al., 2011; Kalkan, 2013; Osinubi et al., 2015).

Soft soils, on the other hand, have traditionally been stabilized by adding lime, ordinary Portland cement (OPC), and/or specific additions like pozzolanic materials to the mix. Studies on the ability of lime, cement as preferable binder constituents to bind soil particles, result in a better material (Farouk and Shahien, 2013; Modarres and Nosoudy, 2015). However, there are chemical technology introduced in soil stabilization to reinforced soils with inadequate engineering features such as Enzymes, liquid polymers, resins, and acids. These are the most frequent chemical substances employed in numerous geotechnical applications. The actual chemical makeup of these brands has not been disclosed owing to the profit-making nature of these products (Rauch et al., 2002, Tingle et al 2007). It's also been noted that the chemistry of OPC produces a lot of carbon dioxide (CO_2) per ton of finished product (Osinubi *et al.,* 2015) and these contributed to the environmental hazard.

The waste materials generated by industrial and agriculture units have also become an environmental hazard that researchers have discovered to be effective for soil development. As a result, substituting OPC in soil stabilization with a geopolymer (i.e material such MTK and RHA admixed with alkaline activators) will lessen the stabilization process and total ecological impact. The applicability of RHA and other agricultural wastes for soil improvement has been reported in several literatures (Yohanna *et al.,* 2016; Sani *et al.,* 2018; Ishola *et al.,* 2019). Furthermore, large-scale garbage burning pollutes the environment and may contribute to ozone layer depletion, necessitating the use of geopolymer. Geopolymer is a mineral composition rich in silica and alumina that is made from basic raw ingredients.

According to (Sarka and Piecha, 2016), geopolymer materials have been employed in the creation of Formula 1 vehicles solely for their remarkable fire resistance, as well as in the production of concrete roads, which are used all over the world in the construction of airport runways. There is a scarcity of information about geopolymer's application as a soil improver.

The impact of RHA and MTK geopolymers on lateritic soil as a road pavement material application is investigated in this study.

MATERIALS AND METHODS

— Soil Sample

Lateritic soil in its disturbed form was taken at Abattoir in Jos, Plateau State, Nigeria (between 9°52′50"N and 8°53′20"E). To avoid organic matter inclusion, the soil was dug to a depth of roughly 0.5 to 1.0 m prior to collection. Soil samples were neatly packaged in plastic stacks and conveyed to the lab for a moisture content test.

— Rice Husk Ash

Rice husk was gathered from Dadin-kowa village in Plateau State, Nigeria's Langtang South local government region. Rice husks were collected in sacks, air dried, and then thoroughly burned in ovens at 1200°C for about an hour. The pulverized ash was sieved by means of BS sieve No 200 and put in storage in a watertight polythene bag. Using a NitonTM XL3t XRF analyser, the oxide composition of the specimens was studied using X-ray fluorescence.

— Metakaolin

The metakaolin for soil enhancement was obtained from Katsina state's processed kaolin clay. After that, the metakaolin was sieved using a 0.75mm sieve.

— Alkaline Activators

The Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) were sourced from a chemical shop in Jos, Plateau State Nigeria. The NaOH and Na_2SiO_3 were added to prepared lateritic soil mixtures by the dry weight of the soil in the ratio of 1:1 as recommended by Gabriel (2018).

— Index Tests

Particle size distribution was done with the use of hydrometer analyses (wet sieving) and mechanical sieve as described in Head (1992). The Atterberg limits(i.e comprising of liquid limit, plastic limit and plasticity index) test was done on soil passing 0.425 mm opening in accordance with British Standards 1377 and 1924 (BSI 1990).

Soil samples prior both particle size distribution and Atterberg limits test were mixed with RHA and alkaline activators (i.e NaOH and Na_2SiO_3) to produce lateritic soil- RHA geopolymer. RHA geopolymer was added to the soil sample in concentrations of 0, 5, 10, 15, and 20% by dry weight of soil. Similar processes were applied in mixing lateritic soil- MTK geopolymer.

— Compaction

Compaction tests were conducted following the procedure outlined in BS 1377 (BSI 1990) to determine the compaction characteristics of the natural and the RHA and MTK geopolymer-treated soil. Standard Proctor (BSL), compaction energy was used. Soil samples prior to compaction test were mixed with RHA and alkaline activators (i.e NaOH and Na_2SiO_3) to produce lateritic soil- RHA geopolymer. RHA geopolymer was added to the soil sample in concentrations of 0, 5, 10, 15, and 20% by dry weight of soil. Similar processes were applied in mixing lateritic soil- MTK geopolymer.

— Statistical Analysis

Statistical evaluation of test results by mean of One-way analysis of variance (ANOVA) was achieved using Microsoft office excel package.

RESULTS AND DISCUSSION

— Index properties

Initial study on the soil properties in its untreated state is presented in Table 1. Proportion of soil passing aperture size 0.075mm was noted to be 44.74%. Liquid limit and plastic limit were 40 and 24.4% while plasticity index of 25.6 was recorded. Comprehensive report of the soil properties are presented in Table 1. Grain size curve of the untreated soil is shown in Figure 1.

Table 1: Geotechnical properties of natural soil

Properties	Quantity
Natural moisture content (%)	12.30
Percentage passing BS No. 200 (%)	44.47
Liquid limit (%)	50
Plastic limit (%)	24.4
Plasticity index (%)	25.6
AASHTO classification	A-7-6
USCS	CL
Specific gravity	2.50
Maximum dry density (Mg/m^3)	1.64
Optimum moisture content (%)	17.80
Color	Reddish brown

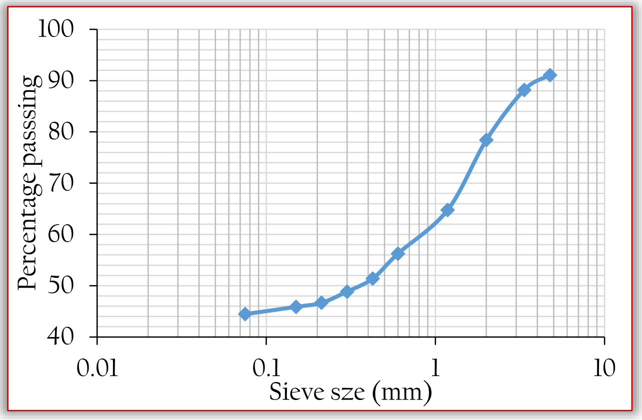

Figure 1: Grain size curve of the untreated soil

— Grain size distribution

The variations of grain size curves of the lateritic soil with RHA and MTK geopolymer are displayed in Figures 2 and 3. The particle size distribution curves for RHA geopolymer initially shifted to the left at 5%, then to the right at 0, 10, 15, and 20%, with respective fines content values of 44.47, 44.59, 38.77, 27.23, and 35.74%, respectively. In the case of MTK geopolymer, a similar tendency with the curve shifting from left to right from 44% (0% M TK) in natural soil to 32% (15% MTK). The right-shifted grain size curves for the two stabilizers show a decrease in the percentage of fines. The decrease in fines fraction with increase in RHA and MTK geopolymer content may possibly be accredited to flocculation and clustering of the lateritic soil with geopolymer mixtures which facilitated the clay fraction to form bigger soil sizes (Akinmade, 2008; Amadi, 2010; Al karagooly, 2012; Portelinha et al., 2012; Etim et al.,2019).

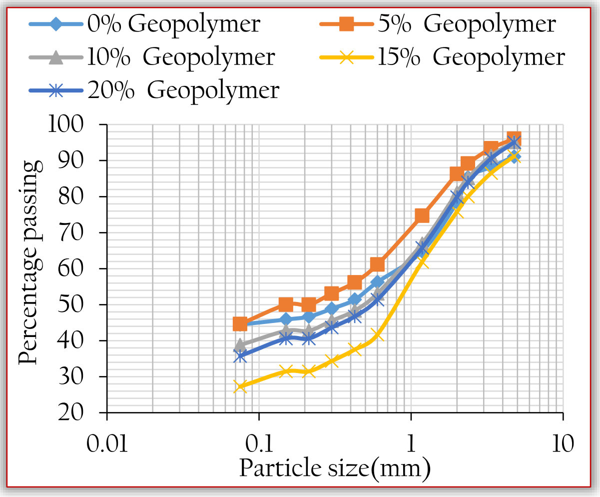

Figure 2: Grain size curve of RHA geopolymer treated lateritic soil

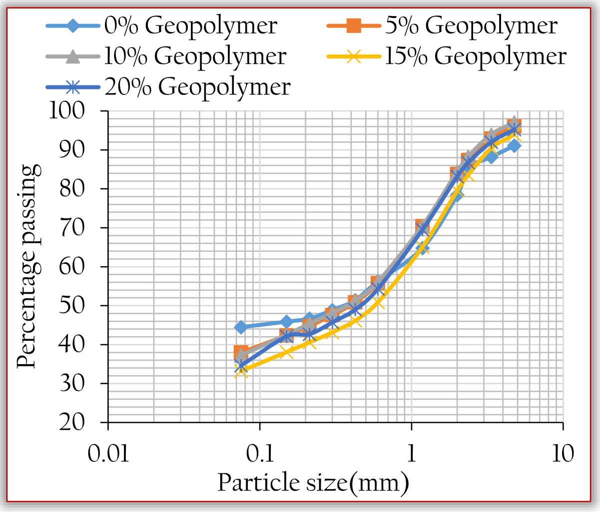

Figure 3: Grain size curve of metakaolin geopolymer treated lateritic soil

— Liquid Limit

The changes in liquid limits with RHA and MTK geopolymer contents for the treated lateritic soil is shown in Figure 4. According to the graph, The liquid limit for both treated soil generally declined from its natural value of 50% to a minimum of 46 and 35% at 20% geopolymer, for RHA and MTK treated soil in that order. Liquid limit values of 50, 47, 50, 54 and 46% were recorded at 0, 5, 10, 15 and 20% RHA geopolymer content in that order. In the case of MTK geopolymer treated soil, limit limits values of 50, 46.9, 40.5, 45 and 35 were recorded at 0, 5, 10, 15 and 20% MTK geopolymer in that order. A comparative study shows that MTK geopolymer recorded lower liquid limit values when compared to RHA geopolymer treated soil. This could be linked to the potency of MTK geopolymer to stiffen the soil more than that RHA geopolymer. A general statement for the decline in the liquid limit for both treatments could be attributed to cation exchange processes in which Ca^{2+} in the mix reacted with ions of lower valence in the clay structure, resulting in flocculation and agglomeration. (Osinubi and Umar 2003; Ramesh et al. (2013) and Oluremi et al. (2017). An analysis of variance (ANOVA) on the liquid limit results (see Table 3) shows that both RHA and MTK geopolymer were statistically significant. For RHA (F_{cal} = 83.597 > F_{crit} = 5.318) and MTK (F_{cal} = 60.251 > F_{crit} = 5.318). However, the effect of RHA was more pronounced when compared to that of MTK.

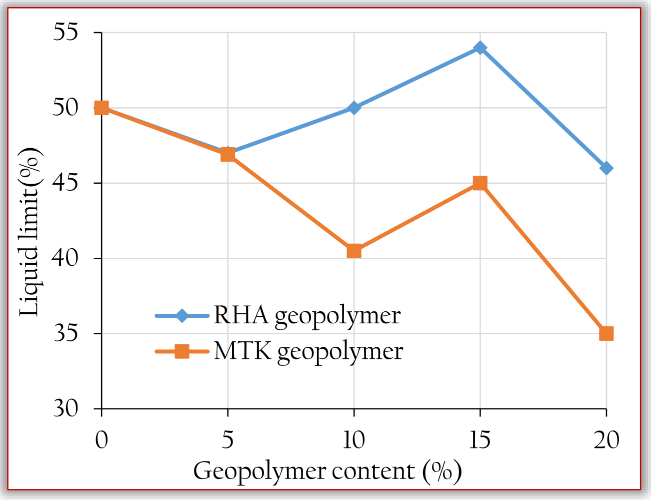

Figure 4. Plot of Liquid limit of RHA and MTK geopolymer treated lateritic soil

Table 2: ANOVA Analysis for Plasticity Properties of Lateritic Soil with RHA and MTK Geopolymer Mixtures

Property	Source of Variation	Degree of freedom	F_{cal}	P-Value	F_{crit}	Remark
Liquid Limit	RHA Geopolymer	1	83.597	1.65E-05	5.318	SS
	MTK Geopolymer	1	60.251	5.42E-05	5.318	SS
Plastic Limit	RHA Geopolymer	1	35.876	0.000327	5.318	SS
	MTK Geopolymer	1	14.298	0.005379	5.318	SS
Plasticity Index	RHA Geopolymer	1	0.593	0.46355	5.318	NS
	MTK Geopolymer	1	0.350	0.570519	5.318	NS

SS=Statistically Significant, NS=Not Significant

— Plastic Limit

The result of the plastic limit test on lateritic soil treated with RHA and MTK geopolymer is shown in the Figure 5. The plastic limit of RHA geopolymer treated soil increased from 50% to 54% at 15% geoplymer content, then decreased to 46% at 20% geoplymer content, whereas the plastic limit of MTK geopolymer increased marginally from 24.37% at 0% metakaolin geopolymer content to 25.7% at 20% geoplymer content. Zaman et al. (1992), Phanikumar et al. (2004), Brooks et al. (2011), and Alkaragooly et al. (2012) have all shown similar decreasing patterns. The decline may perhaps be associated with flocculation and clustering together of the soil rising from cation exchange reactions whereby Ca^{2+} additives reacted with ions of lower valence in the soil structure. ANOVA analysis on the Plastic limit results (see Table 2) shows that RHA and MTK geopolymer were statistically significant. For RHA (F_{cal} = 35.876 > F_{crit} = 5.318) and MTK (F_{cal} = 14.298 > F_{crit} = 5.318). However, the effect of RHA was more evident when compared to that of MTK.

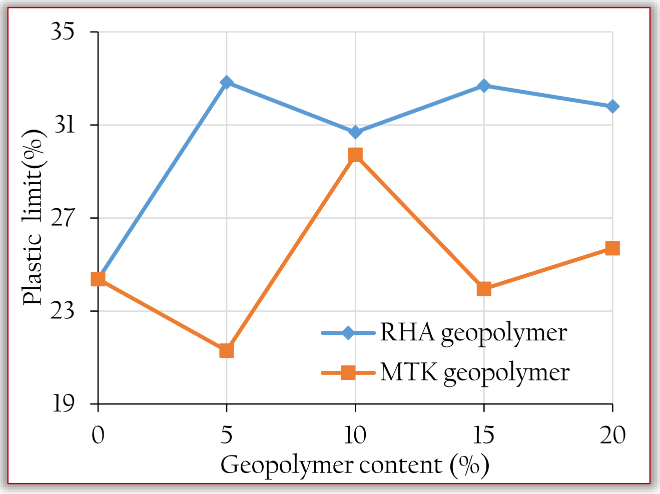

Figure 5. Plot of Plastic limit of RHA and MTK geopolymer treated lateritic soil

— Plasticity index

The result of the plasticity index test on lateritic soil treated with RHA and MTK geopolymer is shown in the Figure 6. The plasticity index of treated lateritic soil in general decreased with increasing RHA geopolymer concentration. At 0, 5, 10, 15, and 20% geoplymer concentration, values of 25.63, 14.18, 19.31, 21.31, and 14.21 were obtained. On the other hand, for MTK geopolymer treated with 0, 5, 10, 15, and 20% content by dry weight of soil caused a decrease in plasticity index with the values 25.63, 24.98, 10.79, 23.95, and 11% respectively. In general, the decline could be linked to formation of cementitious compound and exchange of cations between the soil and the additives (Annafi et al., 2020; Yohanna et al.,2020). ANOVA test on the plasticity index results (see Table 2) shows that RHA and MTK geopolymer were not statistically significant for RHA (F_{cal}= 0.593< F_{crit} = 5.318) and MTK (F_{cal} = 0.350< F_{crit} = 5.318).

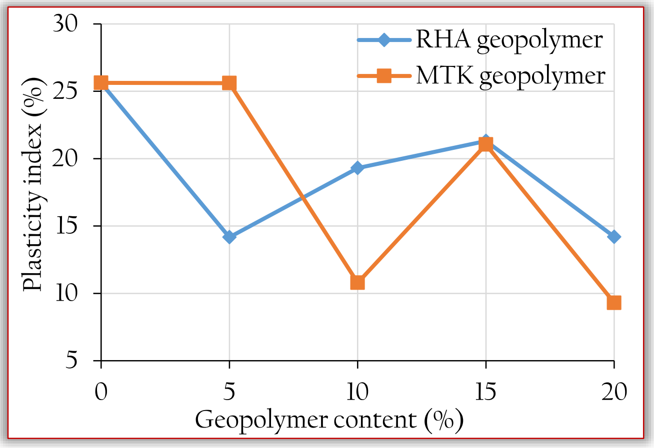

Figure 6. Plot of Plasticity index of RHA and MTK geopolymer treated lateritic soil

— Maximum dry density

The effect of RHA and MTK geopolymer on the MDD of lateritic soil is revealed in Figure 7. It was noted that for treated soil with RHA geopolymer, MDD increased at first and then declined as the geopolymer percentage increased. At RHA geopolymer concentrations of 0, 5, 10, 15, and 20%, MDD values of 1.64, 1.76, 1.75, 1.69 and 1.62 Mg/m³ respectively were recorded. MDD for MTK geopolymer increased from 1.64 mg/m³ at 0% to 1.75 mg/m³ at 5%, then declined to 1.69 mg/m³ 20% MTK content. Although both RHA and MTK geopolymer reported similar trend, MTK geopolymer recorded lower MDD values. Similar trend of increase in MDD values were reported by Phanikumar et al. (2004), Jadhao and Nagarnaik (2008) as well as Kumar and Puri (2013). The observed increase in MDD could be due to RHA and MTK geopolymer that filled the micro pores within the compacted soil fractions and moreover, The recorded trend may possible be associated with the flocculation and clustering of the clayed fractions of the soil linked to interchange of cations of soil and the additives(Yohanna et al,2020). This is in conformity with the discoveries reported by Osinubi (2000), Oriola and Moses (2010; 2011), Amadi (2010), Osinubi and Oyelakin (2012) as well as Ishola et al., (2020). ANOVA analysi on the plasticity index results (see Table 2) shows that both RHA and MTK geopolymer were statistically significant. For RHA (F_{cal}= 5.526> F_{crit} = 5.318) and MTK (F_{cal} = 5.450> F_{crit} = 5.318). However, the effect of RHA was more evident when compared to that of MTK.

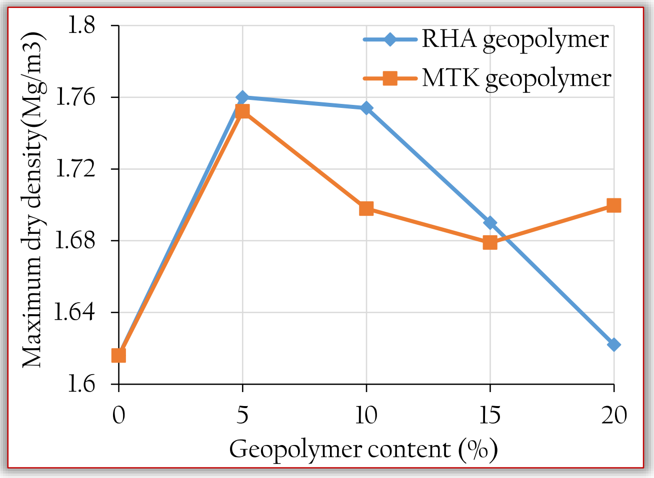

Figure 7. Plot of MDD of RHA and MTK geopolymer treated lateritic soil

Table 3: ANOVA Analysis for Compaction Characteristics of Lateritic Soil with RHA and MTK Geopolymer Mixtures

Property	Source of Variation	Degree of freedom	Fcal	P-Value	Fcrit	Remark
MDD	RHA Geopolymer	1	5.526	0.046624	5.318	SS
	MTK Geopolymer	1	5.450	0.048	5.318	SS
OMC	RHA Geopolymer	1	6.167	0.037911	5.318	SS
	MTK Geopolymer	1	216.225	0.038	5.318	SS

— Optimum moisture content

The changes in OMC of lateritic soil mixtures with RHA and MTK geopolymer content is shown in Figure 8. Initial decrease in OMC values was first recorded for RHA geopolymer content, thereafter increased with higher geopolymer content. OMC values of 17.8, 15.7, 15.5, 22.5, and 23% were recorded at 0, 5, 10, 15 and 20% geopolymer content respectively. In the case of MTK geopolymer treated soil, OMC values of 17.5, 18, 19, 22 and 15.5% were recorded at 0, 5, 10, 15 and 20% MTK geopolymer in that order. Although both RHA and MTK geopolymer reported similar trend, RHA geopolymer treated soil recorded higher OMC values in most cases when compared with that of MTK geopolymer treated soil. The initial decrease could be due to self - desiccation of the mixtures during which all the water was used up, resulting in low hydration. When no water movement to or from soil- Geopolymer matrix is permitted, the water is used up in the hydration until too little is left to saturate the solid surfaces and hence the relative humidity within the paste decreases (Osinubi, 2001; Moses *et.al.,* 2012; Osinubi *et al.,* 2015). An analysis of variance (ANOVA) test on the plasticity index results (see Table 2) shows that the effects of both RHA and MTK geopolymer on lateritic soil were statistically significant. For RHA (F_{cal}= 6.167> F_{crit} = 5.318) and MTK (F_{cal} = 216.225> F_{crit} = 5.318). However, the effect of MTK was more evident when compared to that of RHA.

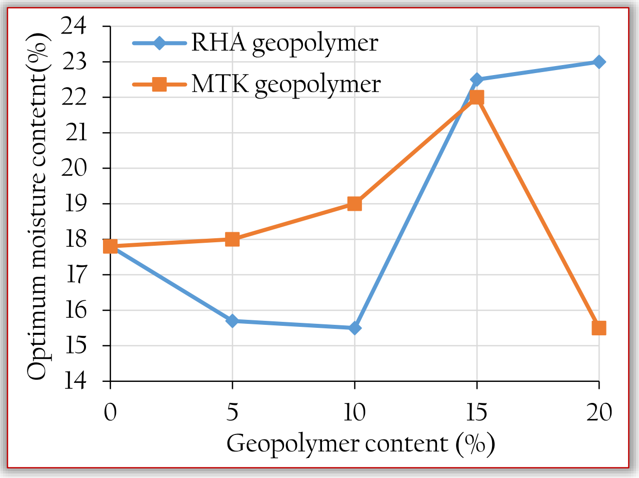

Figure 8. Plot of OMC of RHA and MTK geopolymer treated lateritic soil

CONCLUSIONS

The research work investigated the effect of RHA and MTK geopolymer on the geotechnical properties of lateritic soil. Based on the study, the following conclusions were drawn:

- The proportion of fines decreased with increase in both RHA and MTK geopolymer contents. The liquid limit for both treated soil declined from its natural value of 50% to a minimum of 46 and 35% at 20% geopolymer, for RHA and MTK geopolymer in that order. The plastic limit generally increased while plasticity index decreased for both RHA and MTK geopolymer treated soil.
- Maximum dry density (MDD) increased at first, then later declined. MDD values of 1.64, 1.76, 1.75, 1.69, 1.62 Mg/m^3 and 1.62, 1.76, 1.7, 1.69, 1.71 Mg/m^3 were obtained at 0, 5, 10, 15, and 20% RHA and MTK geopolymer content, respectively. Optimum moisture content (OMC) initially declined and then increased with higher geopolymer content.
- Analysis of variance (ANOVA) reveals that RHA and MTK geopolymer has a substantial influence on the treated soil.
- Based on the result obtained, an optimal blend of 20% RHA and MTK geopolymer blend improved the soil's geotechnical qualities and is recommended for geotechnical engineering applications such as sub-base material for rural roads.

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