Impact of Agricultural Waste Additive on 1-Dimensional Clay Consolidation Behaviour

Emmanuel Emem-Obong Agbenyeku, Edison Muzenda and Innocent Mandla Msibi

Abstract**—**Soil treatment is of vital concern in geoenvironmental and construction engineering in present times as suitable naturally occurring materials are rapidly depleted. Efforts are continually invested towards the resourceful utilization of wastes as fillers, cement enhancers, stabilizers and blenders with little or no significant impacts on the environment. This paper explains the use of a locally available and abundant agricultural waste- Rice husk ash (RHA) in West Africa, Nigeria for the treatment and stabilization of kaolinitic clay (KC) sampled from an active landfill site in Johannesburg, South Africa. The impact of incorporating different percentages of RHA on the compressibility characteristics of a parent compressible landfill KC sample was investigated under a One-dimensional consolidation test. Compacted soil specimens were treated at optimum water content (OWC) and maximum dry unit weight (MDUW) by the addition of agricultural waste material to the parent KC. The compacted specimens were subjected incremental vertical loading in a fixed ring consolidometer device. This was done with a view to closely simulate the waste loading effects from a typical landfill on a treated and parent clay/clayey bottom barrier based on one-dimensional consolidation behaviours. The introduction of RHA waste material to the parent KC revealed an outcome with substantial improvements in compaction characteristics. Hence, the results presented herein showed the agricultural waste to positively increase one-dimensional rigidity while settlement was effectively decreased. From results and analysis, the KC stabilized with RHA can withstand loadings from waste heaps under conditions as were applied in this study. With due recommended examination by geoenvironmental specialists, the stabilized material may be considered as an environmental and cost saving beneficiation approach for use in landfill liners.

Keywords**—***Rice husk ash, Kaolinitic clay, Soil treatment, Soil consolidation*

INTRODUCTION

Silica constitutes part of a poorly crystalline form of reactive agent. It exists in aggregates of sandstones, dolomites and calcretic, and is known to trigger alkaline silica reaction (ASR) expansion. Large quantities of low alkaline cement containing Fly ash (FA) or Ground granulated blast furnace slag (GGBFS) is often used to reduce ASR. The merits of agricultural wastes like RHA, Cassava peel ash and Baggash, and industrial by-products like FA, GGBFS and Silica Fume in stabilization/treatment of some engineering materials have been fairly well documented by [1]-[4]. The expansion of supplementary cementitious materials (SCMs) has become essential in the enhancement of low cost construction materials for self-sufficiency in developing countries. The persistent rise in prices of conventional construction materials and the depletion of natural deposits have called for alternative measures. These alternative materials are to supplement (i.e. partly substitute) the scarce and costly conventional materials in construction works. The utilization of SCMs as admixtures does not only improve properties of engineering materials but protects and conserves the environment by saving energy and natural resources [5]. Series of chemical and elemental tests on RHA collected from a rice milling farm in Nigeria, showed the presence of considerable amounts of Silicon Dioxide, Aluminium Oxide and Iron Oxide [6]. This indicated a chance of significant binding tendencies in the collected ash and as such, qualifies it as a pozzolana [1].

Designs and construction of earth structures in recent times (*e.g.*, as in the case of landfills), take into cognizance the consolidation of deposited clayey profiles due to waste loading effects. According to [7] the utilization of stabilizers in soil treatment or the provision of “sand drains” to accelerate consolidation is a modification approach initiated in improving the compressibility behaviour of soils. This is mostly done in cases where rapidly depleting parent soil profiles at certain construction sites may be partly or entirely unfit to contain the imposed loads from engineered structures. Certain forms of soil modification are comparatively new although the art itself is old. In simple definition, soil treatment/stabilization is the amendment of any property of soil to advance its serviceability outcome. The original purpose of soil alteration as documented by [8] was to augment the strength or stability of soil. However, various methods of soil improvement to either increase or decrease its performance behaviour have emerged in recent times. The exploitation of agricultural wastes as agents for green technology and cost reduction is continually investigated. The ghastly sight of idle and inappropriately contained agricultural waste- RHA is peculiar to most States in Nigeria particularly, regions where rice is vastly cultivated. This agricultural by-product constitutes a nuisance to the general public. In worse cases, causes severe environmental and aesthetic problems. Thus, the idea of integrating these wastes into geo-engineering sought to; (a) facilitate the disposal and conversion of vast amounts of idle waste into

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useful resources and (ii) exploit the waste as a new construction component [9].

Rice is a cereal grain that makes up the most important staple food for a larger part of the world's human population. It is the grain with the second-highest worldwide production, after maize (corn). Rice husk is the outer covering of the rice grain consisting of two interlocking. In West Africa it is an agricultural waste usually generated in large quantities during manual or mechanical threshing and often openly dumped and burnt [10]. As described in [1] RHA is a fine pozzolanic material, which by itself is poorly cementitious but in the presence of lime and water forms a cementitious compound. The pozzolanic value of RHA depends on burning conditions and its colour is dependent on the carbon content of the ash.

The abundance of RHA in West Africa, Nigeria provided the impetus for the study. The impact of this waste additive in improving the one-dimensional consolidation characteristics of a parent KC was therefore investigated. The study also aimed at the reduction of ghastly dumps of ash wastes and their subsequent effects on the immediate environment. Hence, fostering the addition of these waste stabilized products in geo-engineering applications for cost reduction and environmental beneficiation.

MATERIALS AND EXPERIMENTAL APPROACH

Rice husk ash used in this study was gotten as open burnt waste around a local milling farm dump in Nassarawa State, Nigeria where at present over 1000 fully functional mills produce rice for consumption. The reactive amorphous rice husk nodules formed from open air incineration as a disposal method were collected. They were finely crushed and passed through the 75µm sieve. While the natural kaolinitic clay (KC) was collected from an active landfill site in Johannesburg, South Africa. The parent material was sampled from points sufficiently remote from the actual dump space to guarantee a certain degree of purity. The collected samples were chemically and mechanically tested. The various chemical compositions of the respective samples and their index properties are presented in Tables I and II respectively. The chemical constituent of the KC and RHA were determined by X–ray diffraction and fluoresces. The KC chemical compositions appeared to have high cementing tendency while results of the RHA chemical analysis reveals the total content of Silicon Dioxide (SiO_2), Aluminium Oxide (Al_2O_3) and Iron Oxide (Fe_2O_3) to be 73.88% which is above the minimum of 70% specified in ASTM C618. As such, indicates RHA to have significant pozzolanic properties [11].

TABLE I
CHEMICAL CONSTITUENTS OF KC AND RHA

	SiO_2	AL_2O_3	Fe_2O_3	MgO	CaO	LOI
KC	57.2	17.9	13.4	0.91	0.83	-
RHA	63.5	5.43	4.95	6.72	5.44	1.37

The Unified Soil Classification System (USCS) was used in this study for the mechanical index tests, as the samples had very high percentages of fines over 50% passing the No. 200 sieves. The KC had Liquid Limit value above 50 with a plotted Limit above the “A” line on the plasticity chart which classifies it as fat clay-CH. Whereas the RHA additive was classified as low compressible silt-ML. Batches of the parent KC and KC stabilized with 5, 10, 15 and 25% by weight of RHA waste additives were used for the study. Calculated volume of tap water was added to the mixture, the mixture was thoroughly blended and permeable hessian bags were used to cover the samples to allow for proper maturation. The integration RHA as additive to the KC parent material was vital to the soil stabilization approach due to its high pozzolanic properties. The blended mixtures were allowed to equilibrate for 24hrs before compaction. MDUW and OWC for each mix were determined in accordance to the AASTHO compaction method [12]. Cylindrical specimens were compacted by static compaction in 100mm diameter consolidation ring to the required height of 25mm. The inner surface of the ring was greased to reduce friction between the inner surface of the ring and the soil sample during the consolidation process. The homogenized mixture was placed inside the specimen ring with a collar attached, the sample was leveled and filter papers were used to cover its two exposed sides. Porous stone and pressure pad were inserted into the extension collar and the whole assembly was statically compacted in a loading frame to the desired density. The sample was kept under static load for about 25min so as to accommodate for sample expansion.

Table II
CONSTITUENT INDEX POPERTIES

Properties	ASTM/ BSTest		Materials	
			Parent KC	RHA
Particle size	BS:812	Clay+Silt	91.84	87.66
distribution data	BS:812	Sand	8.16	12.34
Liquid Limit	D4318		56	-
Plastic Limit	D4318		29	NP*
USCS**	D2487		CH/fat clay	ML/silt
OWC (%)	D2216		25.2	-
MDUW (kN/m^3)	D698		17.3	-
Specific Gravity	D854		2.53	1.98

**Unified Soil Classification System
*Non-Plastic

DISCUSSION OF RESULTS AND FINDINGS

The paper presents the investigation of consolidation characteristics of a compressible naturally available clay material stabilized with up 25% by weight of RHA additive. This was done with a view to enhancing the behaviour of the KC material such that, the stabilized product may withstand landfill waste loads and other structural induced pressures. To assess improvement in rate and magnitude of consolidation of the stabilized specimens, a range of consolidation parameters through results of one-dimensional consolidation tests were evaluated i.e., coefficient of compressibility, coefficient of consolidation, coefficient of volume change and compression index. Stress levels of 25, 50, 100 and 200kPa to simulate actual landfill waste loads were applied to the specimens in line with [13]. The outcomes are hence, analyzed as followings:

Water-Unit Weight Impact on Modified Kaolinitic Clay

The optimum water content (OWC) and maximum dry unit weight (MDUW) of kaolinitic clay (KC) stabilized with varying percentages of agricultural waste material- RHA was determined. Results obtained for the OWC and MDUW for the respective waste stabilized KC specimens are given in Table III. For the results of the parent KC specimen, OWC and MDUW were found in the range of 25.2% and 17.3kN/m^3 respectively.

Table III
COMPACTION POPERTIES OF RHA STABILIZED KC SPECIMENS

Material constituents	Compaction properties	RHA waste additive (%)				
		5	10	15	20	25
RHA stabilized parent KC	OWC (%)	25.5	25.9	26.5	26.8	27.3
	MDUW (kN/m^3)	16.8	16.3	16.1	15.73	15.5

With respect to the RHA stabilized KC, the OWC varied from 25.5-27.3% and MDUW varied from 16.8-15.5kN/m^3, with increase in RHA percentage. It was observed therefore, that the increase in percentage of RHA simultaneously led to an increase in OWC and a decrease in MDUW. This change may have been due to the relatively low specific gravity of the RHA leading to the reduction in density. Whereas in the case of increased OWC, absorption of water by RHA for hydration of free lime may have been responsible.

Compressibility Coefficient (a_v)

On analysis of the difference in symmetry of void ratio for various values of effective stress and compressibility coefficient (a_v), values for the RHA modified KC specimens, were determined over ranges of consolidation pressures. With regard to the parent KC specimens, the a_v values were found to decrease from 12.7×10^{-4} - $6.1\times10^{-4}m^2/kN$ as the pressure increased from 25-200kPa. This indicates that compressibility of soil decreases with increased effective stress. Following the addition of RHA percentages, it was observed that a_v values varied from 9.6×10^{-4} - $0.47\times10^{-4}m^2/kN$ over the range of effective stresses. For a specific percentage of RHA waste additive, a decreased a_v with increased effective stress was observed. On this note, no definite trend was seen for the various a_v over the different RHA percentages for a particular effective stress. However, a decreased a_v with an increase in RHA additive was observed. This change may be ascribed to the addition of non-plastic silty material to the parent KC specimens. Figs. 1-5 show the variation in a_v values at different effective stresses for the RHA additives. The plotted graphs will assist in economically proportioning RHA waste additive in soil-stabilizer mixtures over a wide range of proportioned parent KC utilized in geoenvironmental works particularly, as bottom liners for engineered domestic waste containment facilities.

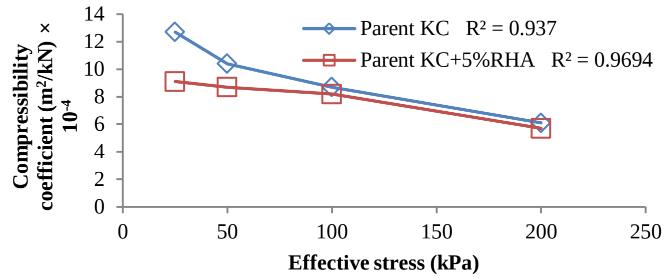

Fig. 1 Effect of 5%RHA stabilizer on KC compressibility coefficient

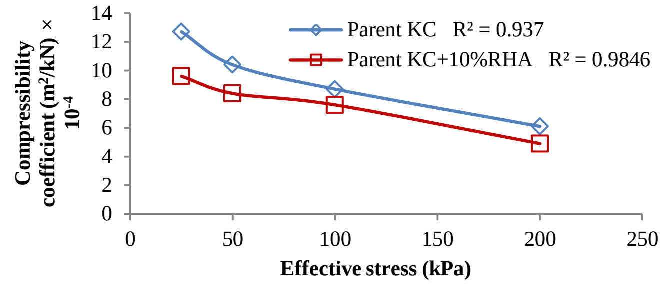

Fig. 2 Effect of 10%RHA stabilizer on KC compressibility coefficient

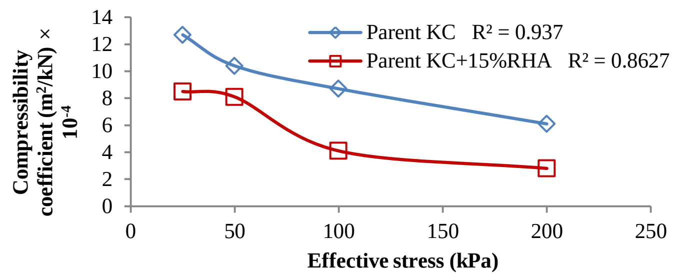

Fig. 3 Effect of 15%RHA stabilizer on KC compressibility coefficient

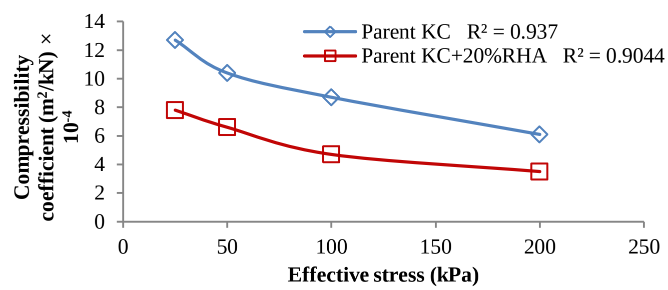

Fig. 4 Effect of 20%RHA stabilizer on KC compressibility coefficient

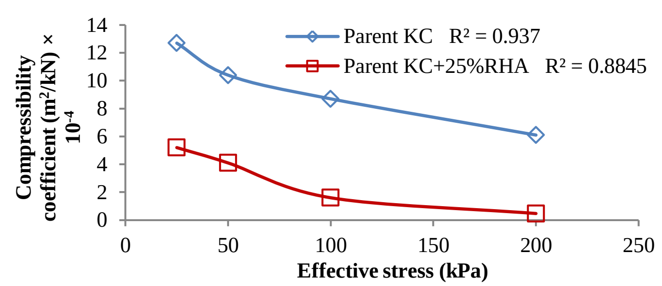

Fig. 5 Effect of 25%RHA stabilizer on KC compressibility coefficient

Volume Change/Compressibility Coefficient (m_v)

On analyzing the deviation in void ratio balance for the different effective stresses, the values of volume change coefficient (m_v) for all RHA stabilized KC specimens were determined across the range of consolidation pressures. The parent KC m_v values were noted to have decreased from 9.79×10^{-4} – $4.23\times10^{-4} m^2/kN$ over the pressure increase from 25-200kPa. This revealed that the coefficient of volume compressibility of soil decreases with the increase in effective stress. From the results gathered, the values of m_v varied from 6.95×10^{-4} - $0.36\times10^{-4} m^2/kN$ for the different percentages of RHA over the various effective stresses. For a particular RHA percentage, a decrease in m_v value with increase in effective stress was observed. No significant trend however, was seen in the variation of m_v for the different percentages of RHA additives on a specific effective stress. Generally, the m_v was found to decreases with every increase in RHA additive. This change may have been caused by the inclusion of non-plastic silty material to the parent KC specimens. The variation in the m_v values based on the varying effective stresses across the percentage of RHA stabilizers are displayed in Figs. 6-10. The following plotted graphs look to help in a cost effective method of material mixes across wide ranges of soil-stabilizer integration.

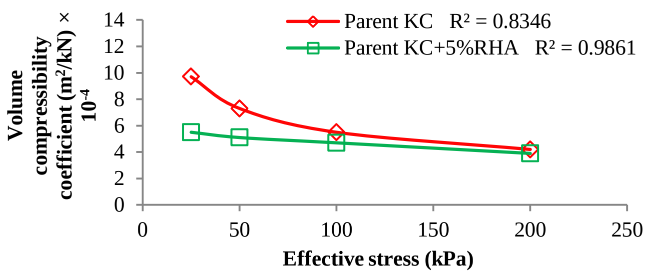

Fig. 6 Effect of 5%RHA stabilizer on KC volume change coefficient

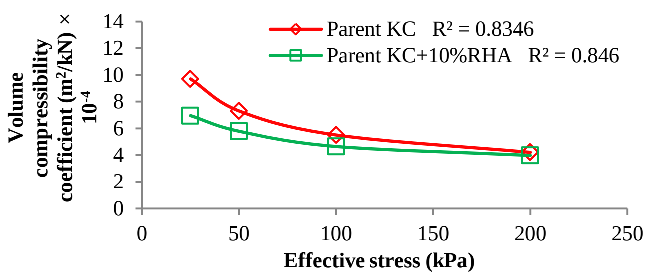

Fig. 7 Effect of 10%RHA stabilizer on KC volume change coefficient

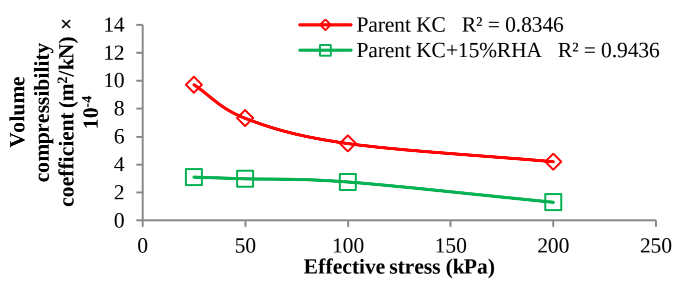

Fig. 8 Effect of 15%RHA stabilizer on KC volume change coefficient

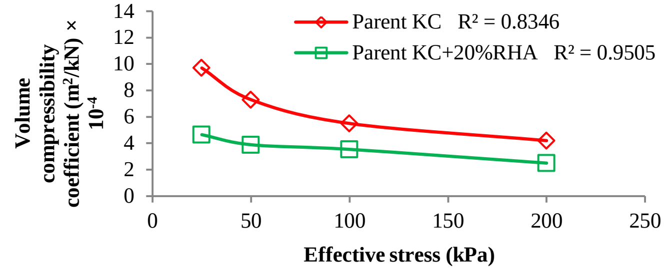

Fig. 9 Effect of 20%RHA stabilizer on KC volume change coefficient

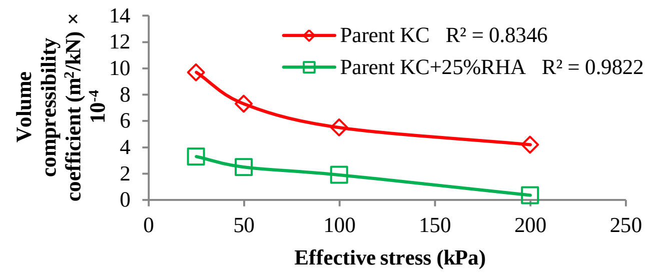

Fig. 10 Effect of 25%RHA stabilizer on KC volume change coefficient

Compression Index (c_c)

Based on the analysis of pressure-void ratio curves on semi-log plots, the compression index (c_c) values for all RHA stabilized KC specimens were determined. The c_c value for the parent KC specimen was determined as a mean value of 0.43. It was however, observed that the c_c values for the different RHA percentages varied from 0.42 - 0.15. The c_c values were found to decrease as RHA additive increased in the respective mixtures. This may have been due to the introduction of the non-plastic agricultural waste additive- RHA to parent KC or as a result of the increased tendency of the RHA stabilized product to withstand compression effects due to the formation of pozzolanic products within the pores of the material. The variation in c_c values over the different RHA percentage additives is graphically represented in Fig. 11. The outcomes of the compression index herein were compared to a similar test conducted using an industrial waste- FA. It was found that the RHA additive had a better effect in reducing the consolidation settlement of the parent KC than the FA additive over similar ranges of effective stresses. The obtained c_c results for the various percentages of RHA stabilized KC specimens can help in proper material mixes for total or partial inclusion in the design of landfill clay lining systems on the basis of settlement due to waste induced loading.

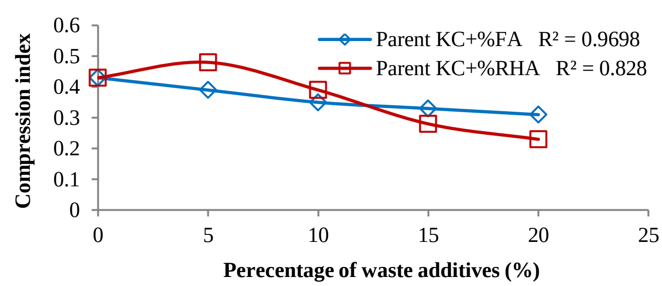

Fig. 11 Effect of RHA additive variation on KC compression index

Consolidation coefficient (c_v)

The coefficient of consolidation (c_v) for RHA stabilized KC specimens over a range of consolidation pressures based on the analysis of difference in dial gauge readings at various time span, was done for specific stress levels with respect to square root of time. The results of c_v for the parent KC was found to decrease from 0.37×10^{-5} - $0.098\times10^{-5}m^2/sec$ as the pressure increased from 25-200kPa. This indicated that the time needed for the KC parent material to reach a given degree of consolidation increases with increase in effective stress. The c_v results for the various percentages of RHA stabilized KC material over the respective effective stresses was found to vary from 1.41×10^{-4} – $0.13\times10^{-4}m^2/sec$. More so, the c_v values were found to decrease with the increase in effective stress at a particular RHA additive. This occurrence revealed that the time required for a given degree of consolidation increases with increase in effective stress. Additionally, as the c_v value increases with increase in RHA proportion for a particular effective stress, it shows that with increase in RHA additive the time required for a given degree of consolidation decreases. This may be due to the nature of the added non-plastic silty material to the parent KC. Variation in c_v values over the different effective stresses for the respective FA stabilizer percentages are graphically expressed in Figs. 12-16. The generated plots may help in time-rate estimation at which a structure will undergo settlement e.g., landfill bottom liner, and the effect of the estimated settlement on the overall service life of the structure.

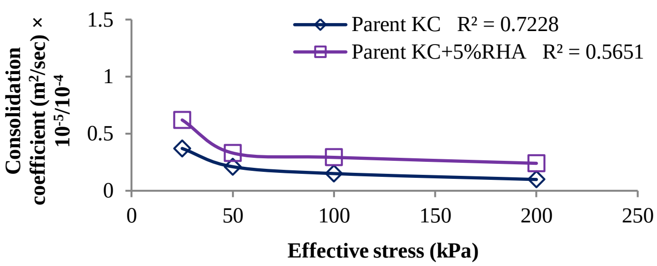

Fig. 12 Effect of 5%RHA stabilizer on KC consolidation coefficient

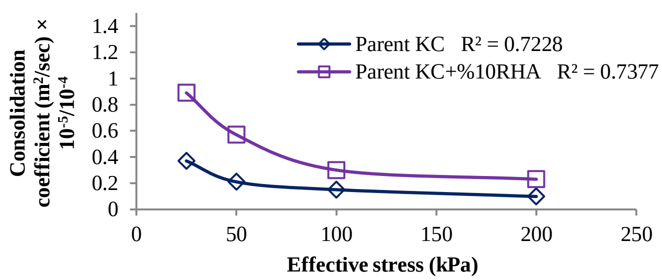

Fig. 13 Effect of 10%RHA stabilizer on KC consolidation coefficient

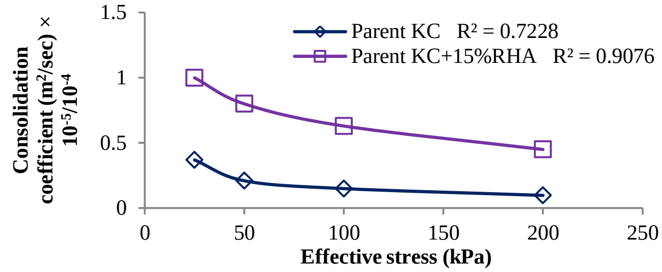

Fig. 14 Effect of 15%RHA stabilizer on KC consolidation coefficient

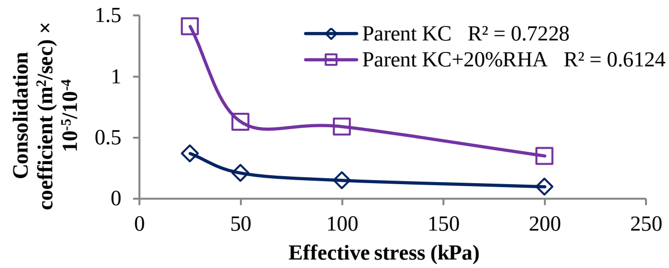

Fig. 15 Effect of 20%RHA stabilizer on KC consolidation coefficient

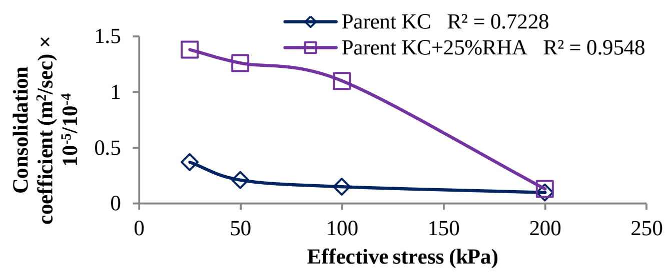

Fig. 16 Effect of 25%RHA stabilizer on KC consolidation coefficient

CONCLUSIONS

The study demonstrates the effect of RHA on the consolidation characteristics of compressible locally available KC. The samples- KC and RHA were respectively collected from an active domestic solid waste disposal site in Johannesburg, South Africa and an operative rice milling farm dump in Nassarawa State, Nigeria. Sequence of consolidometer tests to determine the one-dimensional consolidation behaviours of RHA stabilized KC specimens was conducted. Impact of the various percentages of RHA additives and the different effective stresses on the settlement behaviour of the stabilized products were presented in the paper. From tests and analysis carried out in the study, the following conclusions were drawn:

- Some degree of change was recorded in the MDUW and OWC over the range of RHA percentages integrated into the KC material. An increase in OWC and a simultaneous decrease in the MDUW with increase in RHA additive were however recorded. The relatively low specific gravity of the RHA may have led to the density changes. While the absorption of water by RHA for hydration of free lime may have been responsible for the OWC changes.
- Compressibility analysis of the parent KC and RHA stabilized KC showed that compressibility coefficient

(a_v) had no considerable trend with the variation in the RHA additive for a range of effective stress. A decrease in a_v with an increase in effective stress for percentages RHA additives was however recorded.

- Study of consolidation behaviours of the parent KC and agricultural waste- FHA stabilized KC showed the coefficient of volume compressibility (m_v) to have no significant trend with the variation in RHA percentages over a range of effective stress. However, a decrease in m_v values were observed as the effective stress increased for the RHA proportions.
- The RHA additive lowered the slope of virgin compression curves thereby, lowering the c_c values. When compared with an industrial waste- FA, it was seen that the RHA assisted in the reduction of compression index hence, decreased the consolidation settlement of the stabilized product.
- Furthermore, it was observed that the time required for reaching a certain degree of consolidation decreased as the proportion of RHA additive increased over a range of effective stress. It is therefore pertinent to recognize that closely related outcomes from this investigation have been documented in the works of [14] and [15] although, under varying conditions.

Hence in summary, the exploitation of RHA as a form of agricultural waste for the stabilization of the one-dimensional consolidation characteristics of KC material has to some extent yielded a beneficial outcome. It stands to be a cost reducing factor as well as an eco-friendly and green geoengineering material when converted into a useful product. The results herein can be specifically employed in the design of landfill bottom clay liners among other geoenvironmental components requiring treatment and modification. Nevertheless, investigations *e.g.,* environmental durability, strength behaviour and contaminant leachatability of the stabilized product is recommended.

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