Industrial Waste Modified 1-Dimensional Compressibility of Kaolinitic Clay

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

Abstract**—**The modification of soil has become a major drive in construction and geoenvironmental engineering in recent years. Researches towards the effective incorporation of wastes as cement blenders and enhancers with environmental friendly impacts are increasing. This paper channeled the utilization of commercially available industrial waste- Fly ash (FA) in South Africa towards the modification and improvement of kaolinitic clay sampled from a disposal site. One-dimensional consolidation tests were conducted to investigate the effect of integrating varied proportions of FA on the compressibility behavioral patterns of a parent compressible landfill material. Compacted specimens were modified at optimum water content (OWC) and maximum dry unit weight (MDUW) by the incorporation of an industrial waste material to the parent soil. The generated specimens were subjected to incremental vertical loadings/pressures in a fixed ring oedometer. This was done to simulate the impact of waste loads from a typical landfill on the consolidation characteristics of the modified specimens in a view for use as bottom liners in domestic waste containment facilities. The addition of different proportions of FA waste to the kaolinitic parent clay resulted in considerable improvements in compaction characteristics. Thus, the results of this study revealed that the incorporated industrial waste effectively increased one-dimensional stiffness and as such, successfully decreased settlement. Under adequate strength and operative conditions, the modified kaolinitic clay soil can withstand loadings from waste heaps and after recommended scrutiny by experts, may be initiated into landfill designs as an eco-friendly cost reducing agent.

Keywords**—***Fly ash, Kaolinitic clay, Soil modification, Soil compressibility*

INTRODUCTION

CHALCEDONIC and opaline silica constitute non-crystalline or poorly crystalline forms of reactive aggregates. They are present in flints, sandstones and dolomites, and are responsible for alkaline silica reaction (ASR) expansion. Low alkaline cement used to prevent ASR often contains Fly ash (FA) and Ground granulated blast furnace slag (GGBFS). When used in large quantities, the Class F and C FA are effective in preventing ASR. The benefits of industrial by-products like FA, GGBFS and Silica Fume, and agricultural by-products like Rice husk ash (RHA), Cassava peel ash and Baggash incorporated into engineering materials have been fairly well reported in studies documented by [1]-[4]. Dry dumping or hydraulic deposition of FA into ash dams by power stations is the most common approach of FA disposal in South Africa [5]. Series of chemical and elemental tests on FA collected from one of the active stations, revealed the presence of considerable amounts of free lime, quartz, alumina and iron oxide [6]. This indicated a high likelihood of pozzolanic setting of the ash [7] and is thus, categorized as class-C FA while most of the other stations produced FA with low self cementing potential and is categorized as class-F FA [8]. Experts engaged in design and construction of earth dams, foundations, abutments, embankments and in the present case landfills- are particular about the consolidation of deposited compressible clay/clayey profiles.

Often at times, existing parent soil layers at developing sites may be entirely unsuitable to accommodate loadings from engineered structures. Hence, different modification techniques are employed to improve the compressibility behaviour of soils *e.g.*, the use of additives in soil enhancement or the provision of "sand drains" to hasten consolidation [9]. In simplest term, soil modification/stabilization is the adjustment of any property of soil to advance its engineering performance. While certain forms of soil modification are relatively new, the art itself is old. The original objective of soil alteration as documented by [10] was to increase the strength or stability of soil. However, various techniques of soil treatment developed over time to increase or decrease any engineering property of soil. The utilization of industrial wastes as agents for eco-friendly and economical engineering purpose are continuously on the rise. If left idle and improperly contained, these waste products could pose serious environmental and aesthetic problems. As such, their incorporation into engineering works serves to; (i) facilitate disposal and transformation of waste into a useful resource and (ii) exploitation of waste as new construction ingredient [11].

Since the abundance of FA South Africa provided the impetus for the study, the effect of this waste type in improving compressibility behaviours of kaolinitic clay was investigated. The study also aimed at the reduction of mountainous piles of FA wastes and their potential impact on the environment. As well as enhancing the understanding of compressibility behaviours thereby, encouraging the inclusion of the modified material in geoenvironmental applications in areas where they abound for cost and environmental benefits.

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MATERIALS AND METHODS

Natural kaolinitic clay (KC) was collected from an active landfill site in Johannesburg for this investigation. The parent material was sampled from points sufficiently remote from the actual dump ground to guarantee a certain degree of purity. Whereas, the FA generated by an active power plant in Johannesburg, South Africa was collected from a monitored ash disposal dam. All harvested samples were subjected to a variety of chemical and mechanical tests. The various chemical characterizations of the respective samples and their mechanical index properties are presented in Tables I and II respectively. The chemical constituents of the KC and FA were determined by X–ray diffraction analysis. The total (SiO_2+AL_2O_3+Fe_2O_3) constitution of the sampled FA were greater than 70%. Thus, qualifies it as an active pozzolana [8]. The KC chemical compositions also appeared to have a high cementing tendency.

TABLE I
CHEMICAL COMPOSITION OF KC AND FA

	SiO_2	AL_2O_3	Fe_2O_3	MgO	CaO	LOI
KC	57.2	17.9	13.4	0.91	0.83	-
FA	83.0	8.00	2.65	0.22	0.18	0.55

For the mechanical index tests, the Unified Soil Classification System (USCS) was used in this study as the samples had very high percentages of fines over 50% passing the No. 200 sieves. The KC had a Liquid Limit value above 50 with a plotted Limit above the “A” line on the plasticity chart which classifies it as fat clay-CH. While the FA waste material was classified as silt-ML of low compressibility. Oven dried batches of the parent KC and KC treated with 5, 10, 15 and 25% by weight of FA waste additive was used for the study. Sufficient quantity of water to the desired level was added. The mixture was then thoroughly blended and permeable hessian bags were used to cover the samples. The treatment of the KC parent material with FA was key to the soil modification process due to the highly anticipated pozzolanic reactions. The mixed samples were left to equilibrate for 24hrs before compaction. MDUW and OWC for each mix were determined in conformance 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. After which, 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 swelling of the samples.

Table II
MATERIAL INDEX POPERTIES

Properties	ASTM/ BSTest		Materials	
			Parent KC	FA
Particle size	BS:812	Clay+Silt	91.84	92.34
distribution data	BS:812	Sand	8.16	7.66
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	2.2

**Unified Soil Classification System
*Non-Plastic

RESULTS AND DISCUSSION OF FINDINGS

The paper presents the investigation of compressibility behaviours of a highly compressible naturally available clay material treated with up 25% by weight of FA. This was done with a view to enhancing the suitability of the KC material such that, the modified soil may withstand landfill waste loads and other structural induced pressures. To appraise improvement in rate and magnitude of consolidation of the modified 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 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 an industrial waste material- FA was determined. Values obtained for the OWC and MDUW for the FA waste stabilized KC specimens are given in Table III. As for the values 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 FA STABILIZED KC SPECIMENS

Material combination	Compaction properties	FA waste additive (%)				
		5	10	15	20	25
FA stabilized parent KC	OWC (%)	24.8	24.3	23.9	23.7	23.3
	MDUW (kN/m^3)	17.2	17.19	17.17	17.14	17.1

While for FA stabilized KC, the OWC varied from 24.8-23.3% and MDUW varied from 17.2-17.1kN/m^3, with increase in FA proportion. Hence, it was noted that an increase in percentage of FA led to a decrease in OWC. However, a slight to negligible reduction of the MDUW was observed on addition of FA. The reduced OWC with increased FA content may be accounted for by the non-plasticity of the introduced waste material to the parent KC and the absence of sufficient free lime in FA for hydration reaction.

Compressibility Coefficient (a_v)

Considering the analysis of difference in symmetry of void ratio for various values of effective stress and compressibility coefficient (a_v), values for the FA modified KC specimens were determined over ranges of consolidation pressures. With respect 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 confirms that compressibility of soil decreases with increased effective stress. On the basis of added FA proportions, it was observed that a_v values varied from 10.2×10^{-4} - $0.52\times10^{-4}m^2/kN$ over the range of effective stresses. For a specific proportion of FA waste additive, a decreased a_v with increased effective stress was observed. In this light, no defined trend was seen for the various a_v over the different FA percentages for a particular effective stress. However, a decreased a_v with an increase in FA additive was seen. This change may be attributed 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 FA stabilizer. The plotted curves will aid in economically proportioning FA waste additive in soil-stabilizer mixes over a wide range of proportioned parent KC utilized in geoenvironmental works particularly, as bottom barriers for engineered domestic disposal systems.

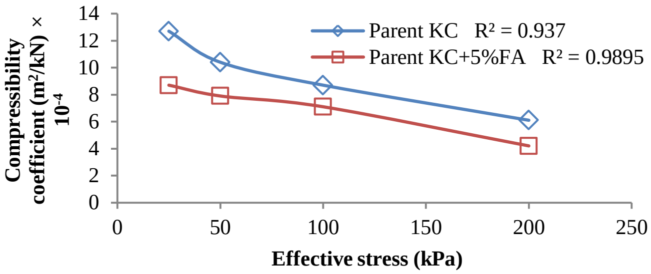

Fig. 1 Effect of 5%FA stabilizer on KC compressibility coefficient

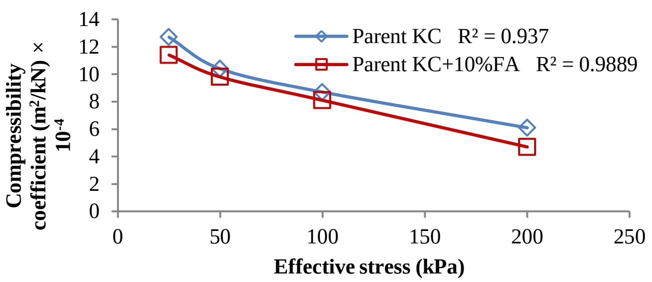

Fig. 2 Effect of 10%FA stabilizer on KC compressibility coefficient

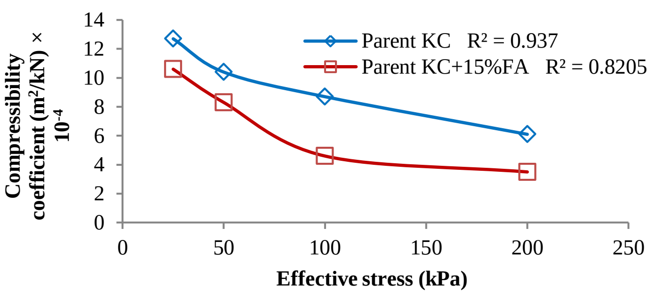

Fig. 3 Effect of 15%FA stabilizer on KC compressibility coefficient

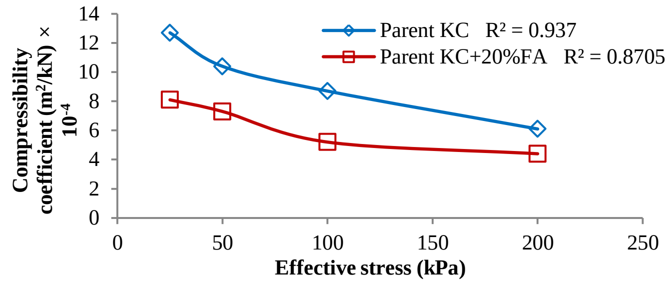

Fig. 4 Effect of 20%FA stabilizer on KC compressibility coefficient

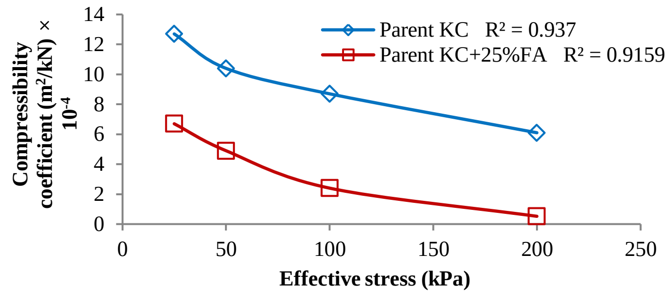

Fig. 5 Effect of 25%FA stabilizer on KC compressibility coefficient

Volume Change/Compressibility Coefficient (m_v)

Following the analysis of deviation in void ratio balance for the different effective stresses, the values of volume change coefficient (m_v), for all FA stabilized KC specimens were determined across the range of consolidation pressures. With reference to the parent KC, m_v values were seen to have decreased from 9.79×10^{-4} - $4.23\times10^{-4}m^2/kN$ over the pressure increase from 25-200kPa. This shows that coefficient of volume change of soil decreases with the increase in effective stress. From the results obtained, the values of m_v varied from 7.24×10^{-4} - $0.28\times10^{-4}m^2/kN$ for the different proportions FA over the various effective stresses. For a particular FA proportion, an observed decrease in m_v value with increase in effective stress was recorded. No recognizable trend however, was seen in the variation of m_v for the different percentages of FA additives on a specific effective stress. Generally, the m_v was found to decreases with every increase in FA additive. This change may have been triggered by the addition of non-plastic silty material to the parent KC specimens. Figs. 6-10 show variation in the m_v values based on the varying effective stresses across the percentage of FA stabilizer. The following plotted graphs sought to aid in a cost effective material proportioning approach in soil-stabilizer mixes over broad ranges.

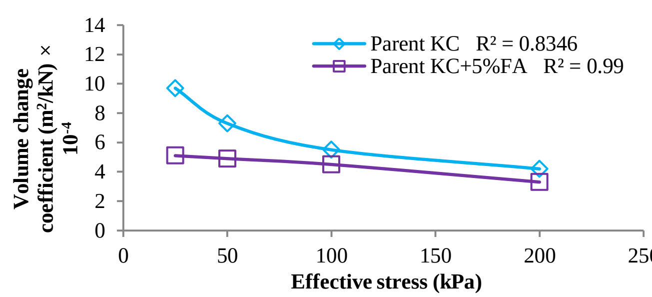

Fig. 6 Effect of 5%FA stabilizer on KC volume change coefficient

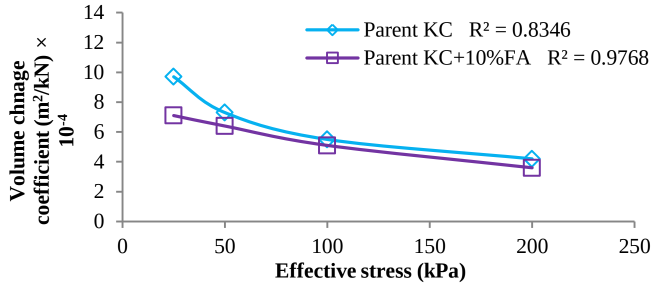

Fig. 7 Effect of 10%FA stabilizer on KC volume change coefficient

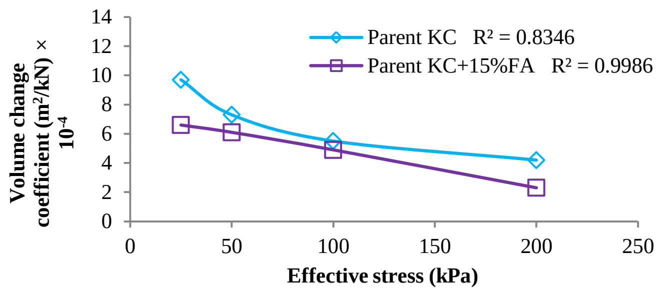

Fig. 8 Effect of 15%FA stabilizer on KC volume change coefficient

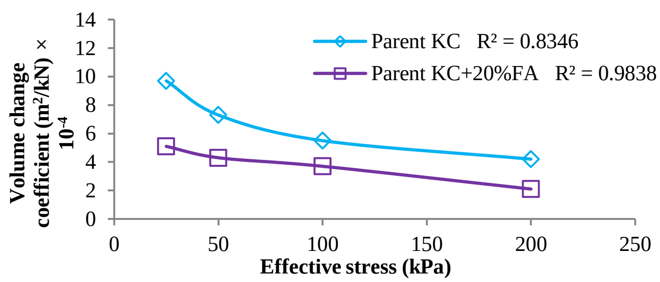

Fig. 9 Effect of 20%FA stabilizer on KC volume change coefficient

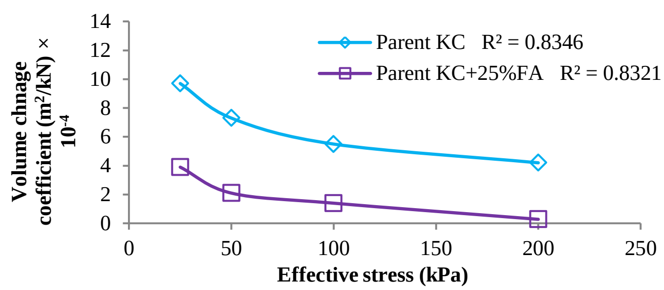

Fig. 10 Effect of 25%FA stabilizer on KC volume change coefficient

Compression Index (c_c)

Considering the analysis of pressure-void ratio curves on semi-log plot, the compression index (c_c) values for all FA stabilized KC specimens were determined. The determined c_c for the parent KC specimen was obtained as a mean value of 0.43. It was however, observed that recorded c_c values varied from 0.39 - 0.31 for the different FA proportions. The c_c value was found to decrease as FA additive increased in the respective specimens. This was accounted for by the addition of the non-plastic industrial waste ash to parent KC. A graphical variation in c_c value over the different proportions of the FA stabilizer is plotted in Fig. 11. As compared to a similar test conducted using an agricultural waste- RHA, it was observed that RHA behaved better than FA in the reduction of consolidation settlement of the parent KC over similar ranges of effective stresses. The obtained c_c values for the various proportions of FA modified KC specimens could aid in proper sample mixtures towards the design of landfill clay barriers on the criteria of waste load induced settlement.

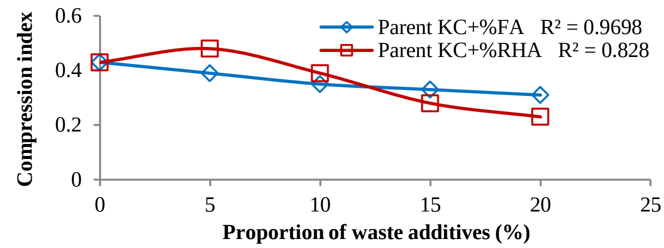

Fig. 11 Effect of FA stabilizer variation on KC compression index

Consolidation coefficient (c_v)

The consolidation coefficient (c_v) for FA stabilized KC specimens over a range of consolidation pressures based on analyzing the variation of dial gauge readings at various time intervals, was done for a particular stress level with respect to square root of time. The value 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 implied that the time required for the KC parent material to reach a given degree of consolidation increases with increase in effective stress. The c_v value varied from 1.47×10^{-4} – $0.16\times10^{-4}m^2/sec$ for the different proportions of FA stabilized KC material over the respective effective stresses. Furthermore, the c_v values were found to decrease with the increase in effective stress at a particular FA additive. This phenomenon indicated that the time needed for a given degree of consolidation increases with increase in effective stress. Again, as the c_v value increases with increase in FA percentage for a particular effective stress, it indicates that with increase in FA 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 curves may assist in time-rate estimation at which a structure will undergo settlement e.g., landfill base, and the effect of the estimated settlement on the overall active design life of the structure.

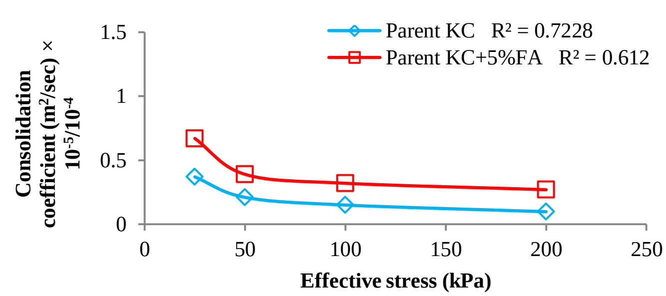

Fig. 12 Effect of 5%FA stabilizer on KC consolidation coefficient

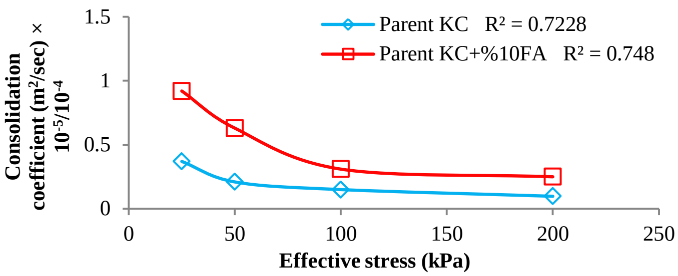

Fig. 13 Effect of 10%FA stabilizer on KC consolidation coefficient

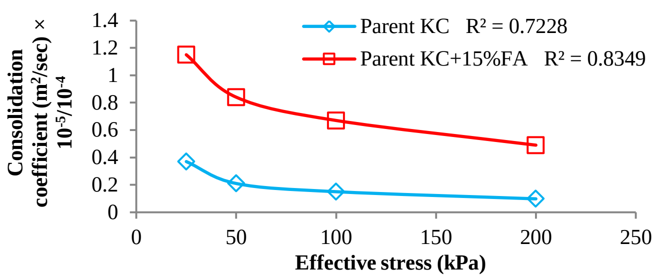

Fig. 14 Effect of 15%FA stabilizer on KC consolidation coefficient

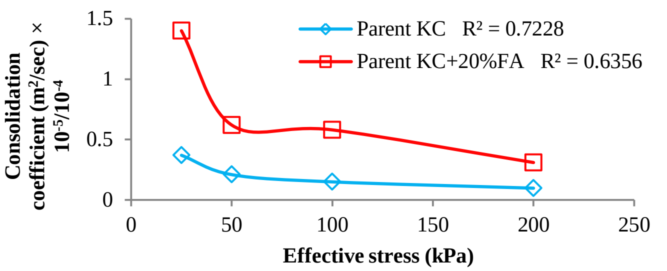

Fig. 15 Effect of 20%FA stabilizer on KC consolidation coefficient

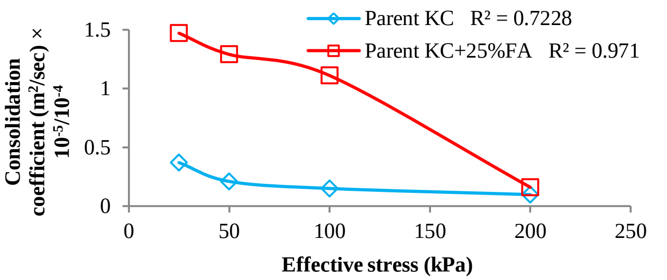

Fig. 16 Effect of 25%FA stabilizer on KC consolidation coefficient

Conclusions

The study demonstrates the influence of FA on the compressibility behaviours of compressible locally available KC. The samples- KC and FA were harvested from an active domestic solid waste disposal site and an operative power plant in Johannesburg, South Africa. Series of oedometer tests to determine the consolidation characteristics of FA modified KC specimens were conducted. Impact of the different percentages of FA additives and the various effective stresses on the settlement behaviour of the stabilized specimens were presented herein. From the tests and analysis, the following conclusions were drawn:

- No definite change was observed in the MDUW over the range of FA percentage incorporated into the KC material. However, a decrease in OWC with increase in FA additive was recorded and accounted for by the non-plastic effect of the material in the parent KC.
- Compressibility analysis of the parent KC and FA stabilized KC indicated that compressibility coefficient (a_v) had no considerable trend with the variation in the FA additive for a range of effective stress. A decrease in a_v with an increase in effective stress for proportions of FA additives was however recorded.
- Study of consolidation parameters of parent KC and industrial waste- FA modified KC revealed the coefficient of volume change (m_v) to have no considerable trend with the variation in FA proportions over a range of effective stress. Although, a decrease in m_v values were observed as the effective stress increased for the FA percentages.
- The FA additive lowered the slope of virgin compression curves thereby, lowering the c_c values. When compared with an agricultural waste- RHA, it was seen that the RHA aided compression index reduction as such, decreased the consolidation settlement of the treated parent KC specimen.
- Additionally, it was recorded that the time needed for reaching a certain degree of consolidation decreased as the proportion of FA additive increased over a range of effective stress. It is important to note that closely related outcomes from this investigation have been documented by [14] and [15] under varying conditions.

Hence in a nutshell, the utilization of FA as a form of industrial waste for the modification of the one-dimensional properties of KC material has to some extent proven beneficial. It appears to be a cost reducing agent as well as an eco-friendly material when transformed into a useful construction resource. The outcomes herein can be specifically initiated into the design of landfill clay barriers among other geoenvironmental structures requiring modified materials. Nevertheless, investigations i.e., cyclic durability and contaminant leachatability of the modified material should be conducted.

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