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Effect of Kaolin-based Zeolite and Cement on Physical Properties of Compacted Laterite Soil

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Abstract
The present investigation evaluates the effect of partial cement replacement with kaolin-based zeolite on some physical properties of cemented laterite soil. Four different cement contents (3, 6, 9 and 12%) and various percentages of cement replacement with zeolite (0, 15, 30, 45, 60, 75, and 90%) were constituted, and then the Atterberg limits together with compaction tests were performed on soil mixtures. The results of the tests indicate that the addition of the cement and zeolite improved the measured physical properties of the soil. The liquid limit and plasticity index decreased with the addition of cement and zeolite leading to enhanced workability of mixtures immediately after treatment. The maximum dry density (MDD) of soil mixtures decreased on average by 6% as a result of zeolite inclusion while the optimum moisture content (OMC) of the mixtures was observed to increase with higher zeolite replacement.

Keywords: Laterite soil, Portland cement, Kaolin-based Zeolite, pozzolanic materials

Introduction

Soil stabilization is a worldwide ground improvement technique which is aimed at enhancing the physical, mechanical and durability properties of local/marginal soil materials in order to create an alternative to traditional dig and dump methods of construction (Amadi and James, 2015; Subramaniam and Banerjee, 2020). Various attempts have been made to improve the properties of soils using different chemical additives. Usually, cement is the most popular chemical additives extensively utilized in various civil engineering projects especially for road construction (Ranaivomanana *et al*., 2018; Subramaniam and Banerjee, 2020). Cement acts as a binder and provides desired reduction in the consistency in addition to improving the strength and stiffness properties of soils. Owing to such advantages, this soil improvement technique is increasingly used in various construction sites (Bahar *et al*., 2004; Sariosseiri and Muhunthan, 2009; Ranaivomanana *et al*., 2018).

Generally, cementation is achieved when soil–cement reactions namely hydration and pozzolanic reactions produce primary and secondary cementitious materials (Subramaniam and Banerjee, 2020). A hydration reaction occurs rapidly when water is added leading to the deposition of three types of primary cementitious materials; calcium-silicate hydrate (CSH) in the forms (C2SHx, C3S2Hx), calcium-aluminate-hydrate CAH in the forms (C3AHx, C4AHx) and hydrated lime Ca(OH)2 deposited as a third cementitious product, where, C, S, A, H are the abbreviations for calcium oxide (CaO), silicate (SiO_2), aluminate (Al_2O_3) and water (H_2O) respectively. Secondary cementitious materials are produced by the pozzolanic reaction between hydrated lime and alumina and silica from clay minerals and provide additional cementitious products of CSH and CAH (Bahar *et al*., 2004; Mola-Abasi and Shoospasha, 2016; Subramaniam and Banerjee, 2020).

However, economic and ecological aspects must be carefully considered in adopting cement as stabilizing agent for soils. The economic problems associated with the use of huge quantities of cement can however be solved by the use of pozzolanic materials or partial replacement of cement by pozzolanic materials. In addition, the pollution caused by cement plants as well

Civil Engineering laboratory from kaolin obtained from Kogi state, Nigeria.
Tap water used to prepare the specimens for laboratory tests was collected from the Civil Engineering Laboratory, Federal University of Technology, Minna.

Method
The physical property tests namely particle size analysis, Atterberg limits, specific gravity and compaction tests were performed on the natural soil sample in accordance with procedures outlined in BS 1377 (1990) while for soil mixtures, test methods specified by BS 1924 (1990) were followed. The soil mixtures were constituted with 3, 6, 9 and 12% Portland cement by weight of soil and each cement content was then replaced by zeolite content in the order of 15, 30, 45, 60, 75 and 90% by weight of the cement. Specimens for compaction tests were prepared using British Standard light (BSL) compaction energy. In each case, the soil specimens were compacted in three layers with each layer given 27 blows from a 2.5kg rammer dropping from a height of 304.80mm above the soil.
In addition, X-ray fluorescence spectrometer (XRF) was used to determine the chemical composition of laterite soil sample, cement and zeolite used in the study.

Results and Discussion

Properties of Materials used in the Study
Laterite soil:
The particle size distribution curve of the soil shown in Fig. 1 indicates that the percentage passing sieve No. 200 is 81.38% while the sand fraction constitutes 18.62%. This suggests that the soil is fine-grained.

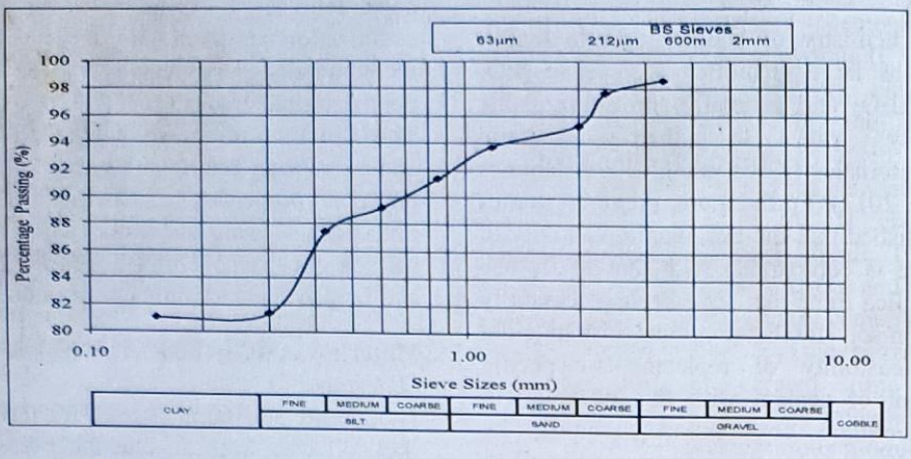

Fig. 1: Particle size distribution curve of the laterite soil used in the study

Based on the Atterberg limits test results, the liquid limits (LL) of the soil was recorded as 46.5% while the plasticity index (PI) was 26.5%. These consistency results together with the particle size distribution results allowed the classification of soil sample in the A-7-6 group of American Association of State Highway and Transportation Officials (AASHTO) classification scheme. On the other hand, the soil is classified as CL according to Unified Soil Classification System (USCS) classification scheme.
The specific gravity of the natural soil was determined as 2.62. This value is slightly lower than that reported by researchers like Amadi and James. (2015) that recorded the value of 2.67 for lateritic soil, but falls in

the range of values (2.6 and 2.75) for soils from the study location (Gbadamosi, 2021). The low specific gravity of the soil is linked to the higher fines fraction and Alumina content (Gidigasu, 1976). The summary of the basic properties of the soil is presented in Table 1.

Table 1 Summary of the Properties of Laterite soil

Property	Quantity
%age Passing sieve No. 200	81.3
Liquid limit (%)	46.50
Plastic limit (%)	20.00
Plasticity Index (%)	26.50
Specific gravity	2.62
AASHTO classification	A-7-6
USCS	CL
Colour	Reddish brown

The oxide composition of the soil sample listed in Table 2 indicate that the major oxide compositions of the soil are SiO_2 (46.27%), Al_2O_3 (28.27%) and Fe_2O_3 (18.04%), all adding up to 66.53% of the total composition.

The zeolite is non-plastic and classified as silt according to the USCS classification system with specific gravity of 2.2. The percentage composition of Iron oxide (Fe_2O_3), Silica dioxide and Aluminium oxide (Al_2O_3) presented in Table 2 for zeolite indicate that the sum of these major oxides is greater than the 70% requirement for class F Pozzolana. This confirms that the zeolite used in the study was a good pozzolanic material. The Portland cement used is a general purpose cement mostly used for concrete and soil stabilization works.

Table 2. Oxide composition of the Laterite soil, Cement and Zeolite used in the study

Oxides	Composition (%)		
	Laterite soil	Cement	Zeolite
SiO_2	46.24	14.65	85.61
Al_2O_3	28.27	3.62	11.54
CaO	0.31	73.13	0.38
Fe_2O_3	18.04	3.74	0.36
K_2O	2.43	0.44	ND
MgO	1.10	1.07	ND
TiO_2	1.77	0.24	0.49
P_2O_5	0.47	0.09	0.57
SO_3	0.42	2.32	0.44
CL	0.26	0.13	0.30

ND – not determined

Combined Effects of Cement and Zeolite on Index Properties of Laterite Soil

The effect of zeolite content on the Liquid limit (LL) of the cement stabilized laterite soil is as reported in Fig. 2. Generally, the results show a decreasing trend in the LL values with higher in cement and zeolite contents. At 0% zeolite replacement, LL soil-cement mixtures reached values ranging from 53 - 55.8% for all cement contents. By introducing and replacing cement with zeolite up to 90%, LL limit values were 47.9, 50, 43.8 and 48% for 3, 6, 9 and 12% cement contents respectively. The decrease may be ascribed to flocculation and agglomeration arising from cation exchange reactions whereby Ca^{2+} in the additives reacted with ions of lower valency in the soil. This result is in agreement with the works of past researchers like Yilmaz *et al.* (2007); Mola-Abasi and Shooshpasha (2016); Mola-Abasi *et al.* (2020) which reported that the addition of cement and zeolite to soil/sand led to reduction in the liquid limit.

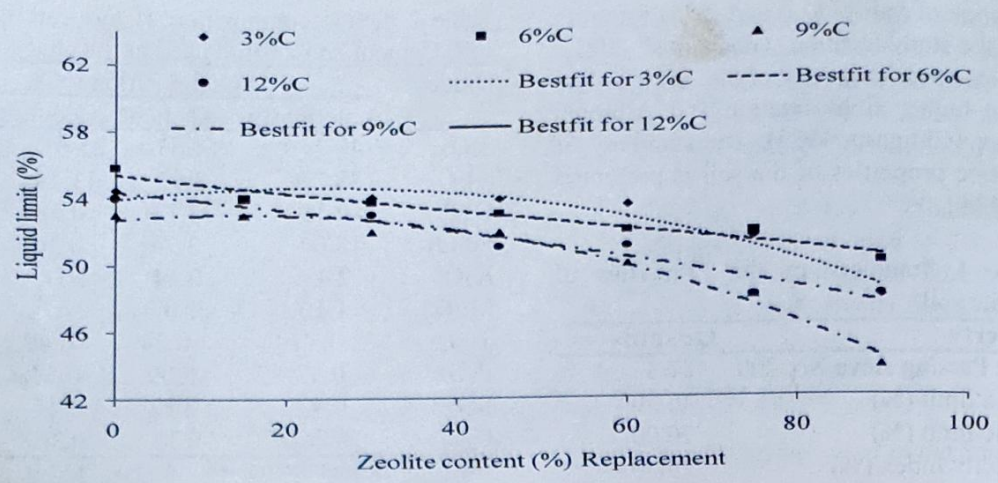

Fig. 2: Variation of Liquid limit with cement and zeolite contents (%) replacement level

Fig. 3 shows the variation of plastic limit for soil-zeolite- cement composites. As can be seen from the figure, the plastic limit increased as the cement content increased. Also, it can be observed that the PL increased as the percentage of zeolite replacement increased in the mixture. The increment in PL might not be unconnected with the flocculation and agglomeration of the clay particles occasioned by cation exchange at the surface due to the introduction of the cement and zeolite (Yilmaz *et al.*, 2007; Rabab'ah *et al.*, 2021).

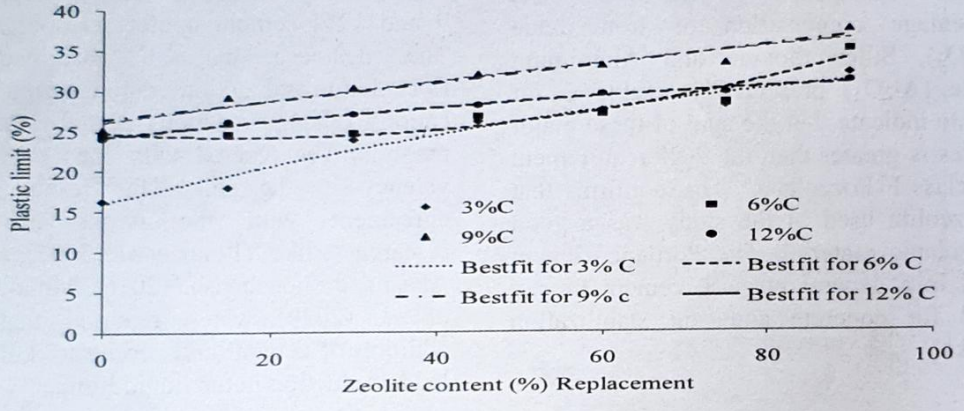

Fig. 3: Variation of PL with Zeolite content (%) replacement level

Similarly, the variation plasticity index (PI) of laterite soil - cement mixtures treated with zeolite is shown in Fig. 4. Generally, the PI decreased as both cement and zeolite contents increased. Plasticity index value of 26.50% recorded for mixture containing 3% cement and 0% zeolite decreased to 6.30% when treated with 12% cement content replaced by 90% zeolite. This could be as a result of reduction in LL of the soil mixtures.

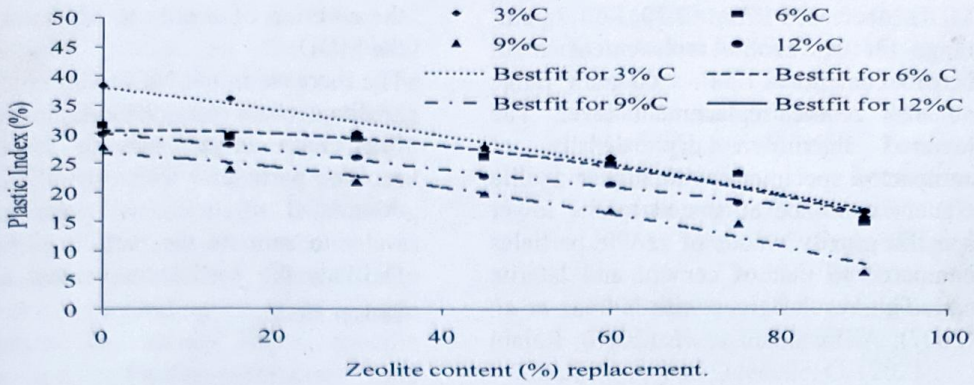

Fig. 4: Variation of PI with Zeolite content (%) replacement level

Meanwhile, the specific gravity of dry soil mixtures reported in Fig 5 indicate that specimens with 0% zeolite replacement (i.e., soil+cement mixtures) had specific gravity which ranged from 2.67 to 2.75 for cement contents of 3 – 12% representing an increase with higher cement content. Generally, for the various soil-cement composites, increase in zeolite replacement led to slight reduction in the specific gravity values which recorded values between 2.4 – 2.47 at 90% zeolite content.

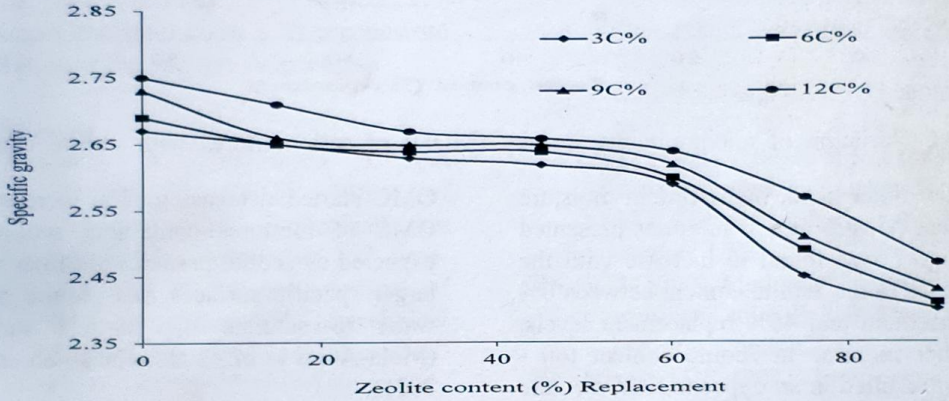

Fig. 5: Variation of specific gravity of solid particle (Gs) with zeolite content (%) replacement level

Combined Effects of Cement and Zeolite contents on Compaction Parameters of Lateritic Soil

The variation of maximum dry density (MDD) of laterite soil - cement mixtures treated with zeolite using BSL compaction energy level is as presented in Fig. 6. Firstly, the result showed an increase in maximum dry density of soil mixtures for every percentage addition of cement. The increase in MDD with cement content is linked to the relatively higher specific gravity of cement (3.15) compared to that of the laterite soil (2.62).

Between 0 - 45% zeolite replacement levels, there was a general decrease in MDD values as zeolite content in the mixture increased. Beyond 45% zeolite replacement, the MDD increased up to

90% zeolite content. For example, the MDD decreased from 1.79 – 1.8g/cm^3 range for 0% zeolite replacement in all cement contents to 1.54 – 1.60 g/cm^3 range at 90% zeolite replacement level. The lowered maximum dry density of compacted specimens with higher zeolite content could be attributed to the lower specific gravity values of zeolite particles compared to that of cement and laterite soil. This result agrees with Yilmaz *et al.* (2007); Al-Swaidani *et al.* (2016); Rajabi and Ardakani (2020) which reported that the addition of zeolite to soil/sand lowers the MDD.

The increase in the MDD values at higher zeolite content (60 – 90%) is linked to the finer with larger specific surfaces of zeolite particles. Consequently, zeolite dominated mixtures will take in more water to saturate the particle surface and facilitate the particle movement to reach denser state.

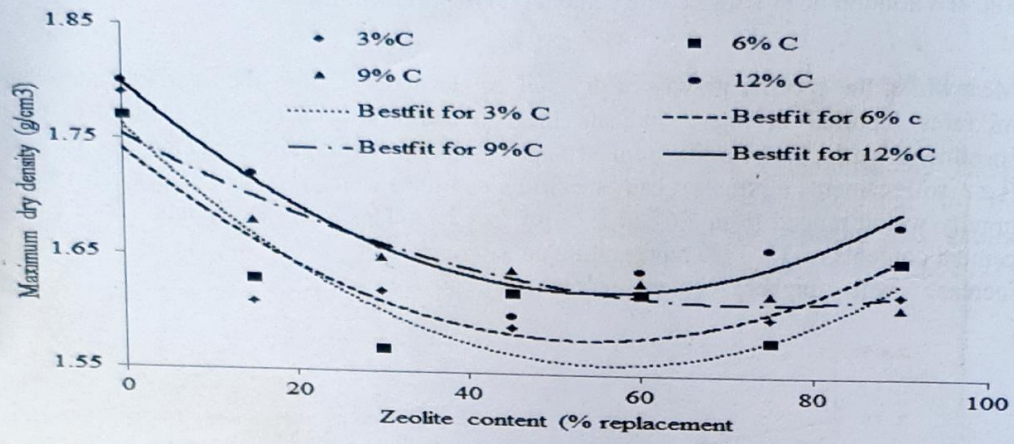

Fig. 6 Variation of maximum dry density (MDD) of soil mixtures with zeolite content

On the other hand, the optimum moisture content (OMC) of soil mixtures presented in Fig. 7 was found to increase with the increase in the zeolite content between 0% replacement and 45% replacement levels. Further increase in zeolite content (60 - 90%) resulted in an opposite trend i.e., the OMC started decreasing. The increase in OMC of mixtures containing zeolite is expected as zeolite particles are finer with larger specific surfaces that require more water to saturate the particle surface (Mola-Abasi *et al.*, 2020; Rabab'ah *et al.*, 2021).

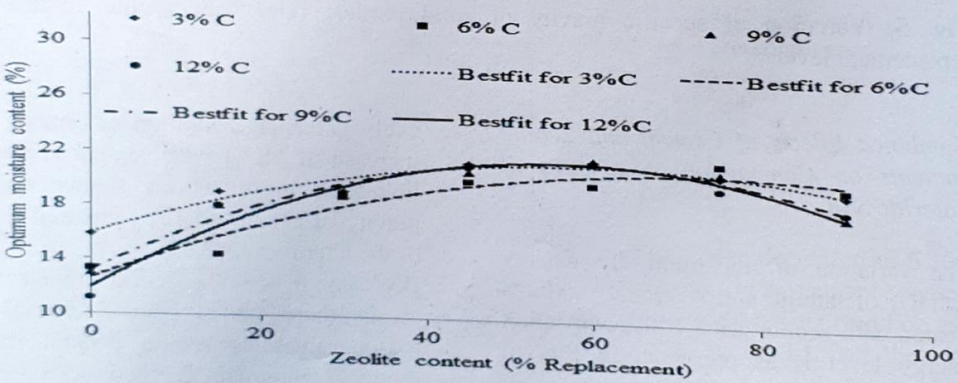

Fig. 7: Variation of Optimum moisture content (OMC) of soil mixtures with zeolite content

Conclusion

This research investigates the effect of kaolin-based zeolite on the physical properties of cemented laterite soil. The mixtures were constituted firstly by adding laterite soil sample with cement (3, 6, 9, and 12% by the dry weight of soil) and then treated with zeolite (0%, 30%, 60%, and 90% of cement content, as replacement material). The index properties, including grain size distribution, consistency limits, specific gravity and compaction parameters were determined in accordance with BS 1377 and BS 1924 (1990) standard test procedures. The following conclusions are drawn from the investigation:

The results obtained from the preliminary tests such as particle size distribution and Atterberg limits indicate that the studied soil can be classified as A-7-6 in the AASHTO soil classification system. The results indicated changes in Atterberg limits, and maximum dry density and optimum moisture content in response to alteration of the additive percentages.

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