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Experimental study on the effect of Zeolite Inclusion on Stress – Strain Characteristics of Laterite soil Stabilized with Cement

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ABSTRACT

The present laboratory investigation studied the effects of zeolite on the stress-strain characteristics of cement treated 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. Atterberg limits, compaction and unconfined compressive strength (UCS) tests were performed on soil mixtures. Specimens for UCS were compacted with British standard light (BSL) effort at optimum moisture contents and cured for 28 days. The results of the tests showed that the addition of cement and zeolite caused a decrease in the liquid limit and plastic index which indicated improved workability of soil after treatment. The maximum dry density (MDD) decreased initially between 0% - 45% zeolite replacement levels while the reverse is the case between 60% -90% zeolite replacement for all cement contents used in the study. Meanwhile, Optimum moisture contents (OMC) increased between 0% and 45% zeolite replacement level. Further increase in zeolite contents` (60% - 90%) resulted in an opposite trend. Finally, the peak stress values obtained from stress – strain curves of mixtures were recorded on specimens with 15% replacement level. Similarly, the lowest values of strain at failure were measured on specimens containing 15% zeolite which represents improvement in the ductile behavior of the mixtures compared to cemented specimens without zeolite.

Keywords: *Kaolin-based zeolite, Laterite soil, Ordinary Portland cement, Stress-strain Characteristics*

1 INTRODUCTION

Some classes of laterite/lateritic soils encountered on project sites are often problematic and gap graded having uneven amount of fines and unstable percentage of coarse particles. These deficiencies are associated with the differences in geological settings, prevailing weathering regimes and rock forming minerals (Sukkarak, 2021).Quite often, most of the areas where Civil Engineering construction projects are located are covered with fine grained laterite/lateritic soils that exhibit insufficient engineering properties needed to provide support for loads from construction equipment and the imposed structural loads during usage (Amadi, 2011). In order to make these deficient laterite/lateritic soils useful as construction materials, stabilization/improvement schemes to enhance their engineering properties are required (Ibrahim *et al.*, 2020).

The use of soil stabilization techniques to improve the engineering performance of soils is quite wide spread across the globe (Kanyi, 2017; Alhaji *et al.*, 2021).Overtime, cement and lime have been the two main materials used for stabilizing soils. The disadvantages of these stabilizers include environmental hazard due to promotion of green house gases which causes global warming and the high energy cost associated with the production process. In order to solve the problems identified above, Liew *et al.* (2011) as well as Alhaji et al. (2021) suggested the use of cement partially replaced with pozzolanic materials as stabilizer for soil improvement purposes. Among the various pozzolanic materials available, zeolite is being considered as a suitable replacement option for cement due to economic, environmental and technical advantages (Al-Swaidani *et al.*, 2016; James *et al.*, 2019). Partial replacement of cement with zeolite can provide additional technical advantages by enhancing the physical and mechanical characteristics of soils through pozzolanic reaction with $Ca(OH)_2$, prevent undesirable expansion due to alkali-aggregate reaction, reduce the porosity of the soil mixtures and improvement in the interfacial microstructure properties of mixtures (Mola-Abasi and Shooshpasha, 2016; Mola- Abasi *et al.*, 2020).

The main advantages in the use of stabilizers are its effects on physical properties such as reduced soil plasticity and higher maximum dry density as well as the mechanical properties of soil such as stress-strain, tensile strength, modulus of elasticity, hardness and fatigue limit. The stress- strain relationship represented by a stress-strain curve is a graph obtained by plotting the values of stresses and strains obtained in uniaxial compression test. Their characteristic is dependent on the strength, age at loading, rate of load and stabilizer properties and type as well as size of specimen. This parameter is used in analyzing the stability of materials (soils inclusive) as part of an engineering system. The curve consists of (i) the elastic phase (ii) plastic yield deformation phase and (iii) the failure deformation phase. The elastic phase is where the material can be deformed and when released will return back to its original configuration, i.e., stress is proportional to strain. At this phase, materials obey the general Hook's law and the slope is defined as the Young's modulus. The plastic phase is the portion where some permanent deformation will occur, even if the load is removed, i.e. the strain is irreversible. Lastly, the failure deformation phase is where deformation is irreversible.

This study therefore presents the stress- strain characteristics of soil mixtures when various percentages of kaolin- based zeolite partially replaces cement in laterite soil- cement mixtures under laboratory conditions.

2 MATERIALS AND METHODS

2.1 MATERIALS

Laterite soil for the investigation was collected from an existing burrow pit located at Sauka-kahuta (longitude 06°28'11''E to 06°32'13'' and between latitude 09°35'22''N to 09°30'36''N) Minna, Nigeria. The cement used for this study is the Dangote brand of ordinary Portland cement designated as CEM II (adopting the terminology used in European standard) and was obtained from a cement depot in Minna, Nigeria. It is general purpose cement mostly used for concrete and soil stabilization (James *et al.*, 2019).

The zeolite on the other hand was synthesized through beneficiation of kaolin obtained from Agbaja deposit from Kogi state, Nigeria in the Civil Engineering laboratory of Federal University of Technology, Minna, Nigeria.

The tap water used to prepare the specimens for the laboratory tests was collected from the Civil Engineering laboratory, Federal University of Technology, Minna.The water is fit for drinking and was also found to conform to BS 3148:1980.

2.1 METHODS

The physical property tests conducted in the laboratory include particle size analysis, Atterberg limits, specific gravity and compaction tests on the natural soil sample in accordance with the procedures outlined in BS 1377 (1990), while for soil mixtures, tests methods specified by BS 1924(1990) were followed. The soil mixtures were constituted with 3, 6, 9 and 12% Portland cements by weight of soil and cement contents were then replaced by zeolite in the order of 0, 15, 30, 45, 60, 75 and 90% by weight of cement.

Specimens for compaction were prepared using British Standard Light (BSL) compacting energy. The engineering test performed on the specimens was the unconfined compressive strength (UCS) tests. From the results, stresses and strains from each test were computed and presented in stress-strain curve.

Finally, X-ray fluorescence spectrometer was used to determine the oxide composition of laterite soil sample, cement and zeolite used in the study.

3 RESULTS AND DISCUSSION

3.1 PHYSICAL PROPERTIES OF THE LATERITE SOIL

The physical properties of the laterite soil were as summarized in Table 1. The natural moisture content of the untreated soil was found to be 17.01%. The particle size distribution curve of the soil shown in Figure 1 indicates that the percentage passing sieve No.200 is 81.38% while the sand fraction constitutes 18.62%. This indicates that the soil is fine-grained. The result of the Atterberg limits revealed that the liquid limit (LL) of the soil was 46.5%, the plastic limit (PL) 20.00% while the plastic index (PI) was 26.50%. These results together with the result of the sieve analysis allowed the classification of the soil sample in theA-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). The specific gravity of the untreated (natural) soil was found to be 2.62, a value that is slightly lower than that reported by researchers like Amadi and James (2015) which recorded the value of 2.67 for lateritic soil, but fall in the range of values(2.6 - 2.75) for soils from the study location (Gbadamosi,2021). The low specific gravity of the soil is attributed to higher fines fraction and Alumina content (Gidigasu, 1976).

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.

3.2 CEMENT

The cement used for the study was the Dangote brand of ordinary Portland cement conforming to BS 12:1991. The specific gravity of the cement is 3.15, while the oxide composition is as listed in Table 2.

3.3 ZEOLITE

The zeolite is non-plastic and classified as silt with specific gravity of 2.2. The percentage composition of iron oxide (Fe_2O_3), silica dioxide (SiO_2) and aluminum oxide (Al_2O_3) presented in Table 2 for the zeolite added up to 97.51% which is greater than 70% requirement for class F pozzolana. This confirms that the zeolite used in the study was a good pozzolanic material.

TABLE 1: ENGINEERING PROPERTIES OF LATERITE SOIL USED IN THE STUDY

Parameter Description	Value
Specific gravity	2.62
Percentage passing no. 200 sieve (%)	81.3
Liquid limit (%)	46.5
Plastic limit (%)	20
Plastic Index (%)	26.5
Classification (AASHTO)	A-7-6
Classification (USCS)	CL
Maximum dry density (kN/m^3)	1.59
Optimum moisture content (%)	18.48
Unconfined compressive strength (kN/m^2)	82.65
Colour	Reddish brown

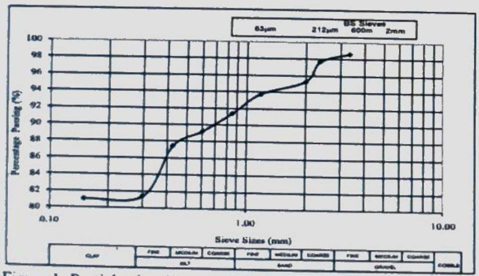

Figure 1: Particle size distribution of the laterite soil used in the study

TABLE 2: OXIDE COMPOSITION OF 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	0.43	2.32	0.44
CL	0.26	0.13	0.30

3.4 EFFECTS OF CEMENT AND ZEOLITE ON INDEX PROPERTIES OF LATERITE SOIL

The effect of zeolite content on the Atterberg limits of the cement stabilized laterite soil is as presented in Figures (2-5). Generally, the results show a decreasing trend in the liquid limit (LL) values with higher cement and zeolite contents. At 0% zeolite replacement, the LL of 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 values were 47.9, 50, 43.8 and 48% for 3, 6, 9 and 12% cement contents respectively. The decrease may be linked to the flocculation and agglomeration arising from cation exchange reaction whereby Ca^{2+} in the additives reacted with ions of lower valency in the soil. This result agrees with the outcome of past studies 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. As can be seen in Figures (2-5), the plastic limit increased as the cement and zeolite contents increased. The increment in plastic limit (PL) recorded for all cement contents used in the study 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). The variations of plastic index (PI) are as depicted in Figures (2-5). Generally, the PI decreased as both cements and zeolite contents increased. The plasticity index of 26.50% recorded for the natural soil decreased to16.89% when treated with 12% cement content replaced by 90% zeolite. This could be as a result of the reduction of the LL of soil mixtures.

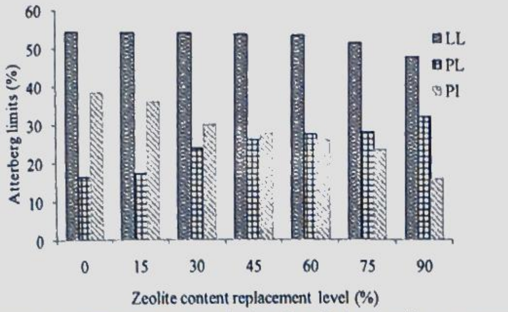

Figure 2: Changes in Atterberg limits of studied soil with 3% cement content

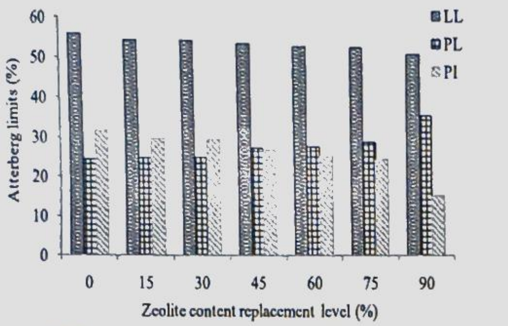

Figure 3: Changes in Atterberg limits of studied soil with 6% cement content

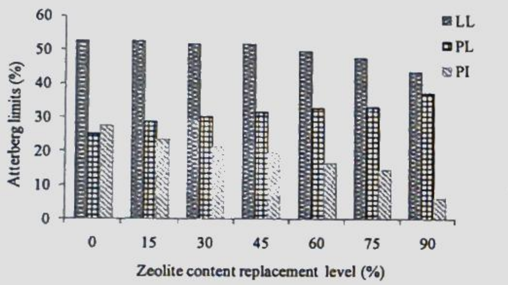

Figure 4: Changes in Atterberg limits of studied soil with 9% cement content

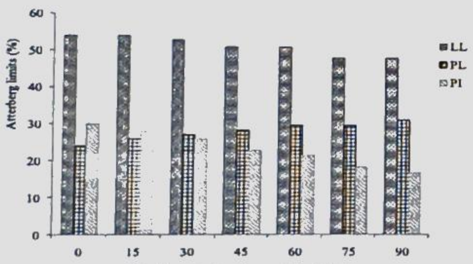

Figure 5: Changes in Atterberg limits of studied soil with 12% cement content

3.5 EFFECTS OF CEMENT AND ZEOLITE CONTENTS ON SPECIFIC GRAVITY

The specific gravity of the dry soil mixture reported in Figure 6 indicates that specimens with 0% zeolite replacement (i.e. soil+ cement mixtures) has specific gravity which ranged from 2.67 to 2.75 for cement contents of 3-12% representing an increase with higher cement content. The increase could be attributed to a material of higher specific gravity (cement- 3.15) replacing a lighter material (i.e. laterite soil) with a specific gravity of 2.62.

Generally, for the various soil-cement composites, increase in zeolite replacement level led to slight reduction in the values of specific gravities which recorded values between 2.40 and 2.47 at 90% zeolite content. The slight reduction is as a result of lighter material in terms of zeolite (specific gravity of 2.2) replacing heavy material in terms of cement (with specific gravity of 3.15) in soil mixtures.

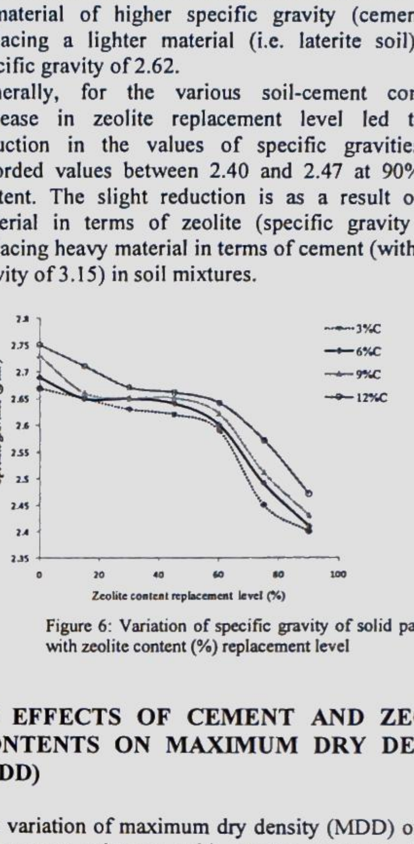

Figure 6: Variation of specific gravity of solid particle (Gs) with zeolite content (%) replacement level

3.6 EFFECTS OF CEMENT AND ZEOLITE CONTENTS ON MAXIMUM DRY DENSITY (MDD)

The variation of maximum dry density (MDD) of laterite soil-cement mixtures with zeolite contents for BSL compaction is as presented in Figure 7. It was observed that the MDD values decreases with increase in zeolite contents (from 0%-45% zeolite content) before increasing in values from 60%- 90% zeolite contents in the soil-cement mixtures and for all cement contents used for the study. The initial decrease in MDD can be attributed to the replacement of cement by zeolite which has a relatively low specific gravity of 2.2 when compared with that of cement that is 3.15. Between 60%-90% zeolite contents in the mixtures and for 3% C-12% C contents; there was increase in the value of MDD, i.e. from 1.629/cm^3 at 3% C content to 1.68g/cm^3 at 12% C content. The increase in MDD values can be attributed to a decrease in the surface area of clay fraction of the soil arising from the substitution of laterite soil with cement and zeolite. In general, the result shows an increase for every percentage addition of cement. The increase in MDD with cement content is attributed to the relatively higher specific gravity of cement (3.15) to that of the soil (2.62) (Alhassan and Mustapha, 2006).

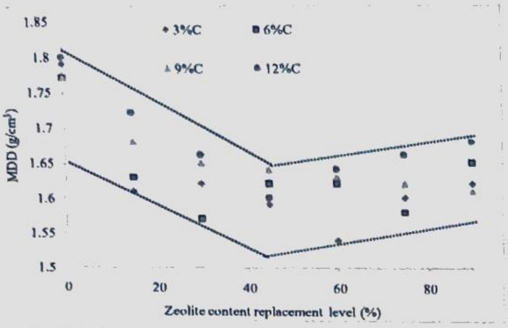

Figure 7: Variation of maximum dry density (MDD) of the soil-cement mixtures with zeolite content

3.7 EFFECTS OF CEMENT AND ZEOLITE CONTENTS ON OPTIMUM MOISTURE CONTENTS (OMC)

Figure 8 shows the variation of Optimum moisture content (OPC) of laterite soil-cement mixtures with zeolite contents for BSL compaction. It can be seen that the OMC increases 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). The decrease in OMC between 60%-90%zeolite content replacement level might be attributed to reduction in water demanded for hydration purposes as the level of cement contents reduces greatly in all soil-cement mixtures as the level of zeolite increases to 90% replacement in various soil-cement mixtures.

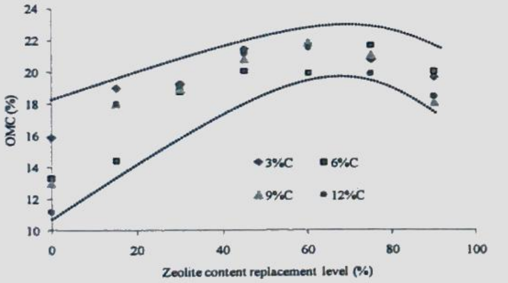

Figure 8: Variation of Optimum moisture content (OMC) of soil-cement mixtures with Zeolite content

3.8 STRESS-STRAIN CHARACTERISTICS OF MIXTURES

The stress-strain relationships obtained from UCS tests for mixtures stabilized with3% C, 6% C, 9 % C at 12% C at 0%, 15%, 30%, 45%, 60%, 75% and 90% zeolite replacement levels are presented in Figures (9-12).It is shown that the maximum axial stress increased significantly due to cement stabilization and the strain corresponding to the peak axial stress decreased. For example, at 3% C with 15% zeolite replacement level, the peak axial stress was 637.50 kN/m^{2}and strain at failure of 1.64%. When cement content was increased to 12%, at zeolite replacement of 15%, the peak stress increased considerably to 3480.90kN/m^2 with a corresponding strain of 0.66%. Thus, mixtures with the greatest strength were achieved at zeolite replacement levels of 15% for all cement content.

When additive contents were increased, large strength values were obtained for lower axial strain values. At high zeolite content (60-90%) the mixtures suffer from less effective cementation due to increase granular nature and hence yield low strength due to tensile cracking upon uniaxial loading.

The introduction of zeolite resulted in slight decrease of strain at failure. However, subsequent increase in zeolite content led to increase in the peak strain when compared to specimens treated without zeolite (Figure 13). Thus utilizing zeolite in cemented soil increases the strain at failure and reduces the brittleness of the mixtures.

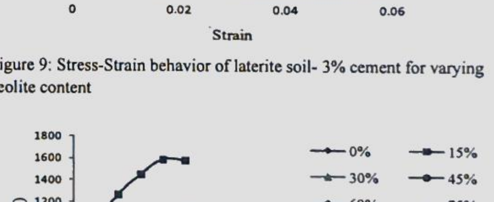

Figure 9: Stress-Strain behavior of laterite soil- 3% cement for varying zeolite content

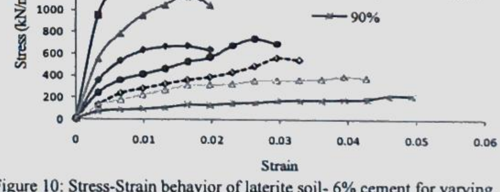

Figure 10: Stress-Strain behavior of laterite soil- 6% cement for varying zeolite content

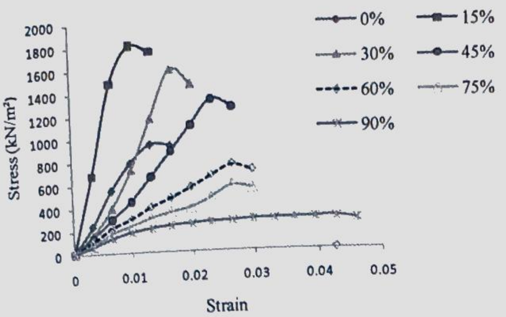

Figure 11: Stress-Strain behavior of laterite soil- 9% cement for varying zeolite content

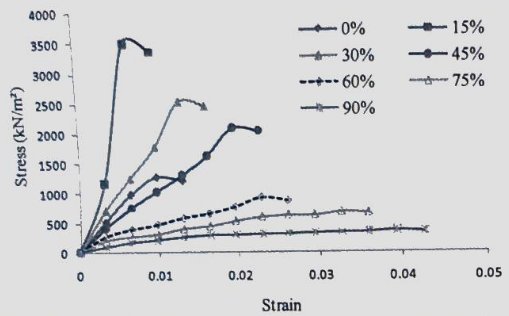

Figure 12: Stress-Strain behavior of laterite soil- 12% cement for varying zeolite content

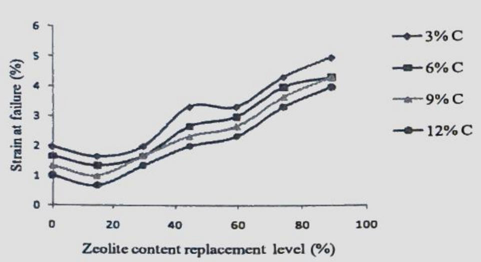

Figure 13: Variations of Strain at failure for different cement contents for varying zeolite content

4 CONCLUSION

Stabilization of a representative laterite soil was carried out using four cement contents that were replaced at 0, 15, 30, 45, 60, 75 and 90% zeolite content. From the results obtained, the following conclusions can be drawn. The results of the tests showed that the addition of cement and zeolite improved the measured physical properties of the soilwhich indicates improved workability of mixtures after treatment. The maximum dry density (MDD) decreased between 0% - 45% zeolite replacement level and thereafter increased up to 90% replacement for all cement contents used in the study. Optimum moisture contents (OMC) on the other hand increased between 0% and 45% zeolite content at higher concentrations. While the peak stress increased with increase in cement, the strain at failure decreased with increase in the amount of cement added to the mixture. Furthermore, both the peak stress and strain at failure were obtained in specimens containing 15% zeolite which represents remarkable improvement in the ductile behavior of the mixtures compared to the cemented samples without zeolite and this finds application in road pavement design.

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