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Research Paper

Stabilization of Lateritic Soils Using Steel Slag

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ABSTRACT: *Lateritic soils which are the most wide-spread construction material for roads are known to have poor engineering properties such as high plasticity, poor workability, low strength, high permeability, tendency to retain moisture and high natural moisture content. This research evaluated the use of steel slag for the stabilization of lateritic soils for the purpose of improving their load-carrying capacity. A reddish-brown lateritic soil, classified as CL according to the unified soil classification system respectively, was treated with up to 10% pulverized steel (an industrial waste materials) by dry weight of soil. Firstly, the chemical analysis of the steel was investigated using X-ray fluorescence spectroscopy. Tests were carried out to determine the index properties, compaction characteristics, maximum dry density, (MDD), optimum moisture content (OMC), California bearing ratio, (CBR) and unconfined compressive strength, (UCS) of the treated natural soil. Test results showed that the Atterberg limits (liquid limit, plastic limit and plasticity index) generally decreased, while the specific gravity of soil-steel slag mixtures increased with higher steel slag content. Generally, the CBR and UCS increased with higher steel slag content. An 8% optimal stabilization of the A-7-6 soil with steel slag satisfactorily met the general specifications requirement for subgrade materials.*

KEYWORDS: *laterite, lateritic soil, steel slag, stabilization, fluorescence spectroscopy*

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I. INTRODUCTION

The need for high-quality construction materials is growing, yet affordable options are increasingly scarce. At the same time, as a result of more severe environmental regulations and a scarcity of suitable, local disposal sites, disposing of industrial waste or by-products has grown more difficult and expensive. Steel slag is a waste product from the production of steel; however, it may be repurposed and is already in use outside of the metal sector. It is widely utilized in the construction sector as a component of concretes, pavements, and roofing granules, according to [1].

The use of industrial by-products from the steel-making industry like steel slag has been established in a number of applications in the construction industry [2-3]. Steel slag is produced at many stages and by various processes during the steel-making process. Steel slag is utilized as a roadbed material because of its high bearing capacity and hydraulic qualities, according to [4]. Steel slag can expand when it comes into contact with water because it contains free lime (CaO). As a result, it is only used when it has been stabilized. It is utilized as a sand substitute as a ground improvement material (sand compaction pile material) in port and harbor building projects, taking use of its qualities of having a higher mass per unit volume and a higher angle of internal friction than natural sand. Lateritic soils are found all across the world, particularly in the tropics. Because of their non-swelling characteristics, they are frequently used as imported fill material for the prepared subgrade in various types of road projects. Of the various soil types that occur in the tropics and subtropics, laterite is one of the most common and is of particular interest in building and road construction.

AASHTO classifies soils into seven groups, A-1 to A-7. According to [5], most lateritic soils for road construction fall within the A-2, A-6 and A-7 groups and no lateritic soils have been found in the A-3 and A-5 groups.

Lateritic soils have been employed widely in a variety of earthwork projects, including dams, highway embankments, and structural layers. The fact that lateritic soils are locally available in most countries necessitates more investigation into their potential as a reliable and lasting building material. To stabilize it, several studies [6-8] have been conducted.

II. METHODOLOGY

Preliminary tests (natural moisture content, specific gravity, sieve analysis and Atterberg's limits) were performed on the three soil samples. Steel slag was added to each of the soil samples in 5, 8 and 10 % by weight of the samples. Atterberg's limits and engineering property tests (compaction, California bearing ratio (CBR), unconfined compression, permeability) were performed on the samples. The effects of steel slag as stabilizing agent on the samples were thereafter determined. The procedures for the various tests were carried out in accordance with [9] and [10]. Chemical Composition of Steel Slag: The slag reactivity and mineralogy were estimated from X-ray diffraction (XRD) and X-ray fluorescence (XRF). The XRD analysis for the steel slag produced bad spectra, as reported by the laboratory officials at Centre for Energy and Research Development (CERD), Ahmadu Bello University, Nigeria. However, XRF was carried out on the slag sample in CERD. The XRF machine could not detect elements with atomic numbers within the range of 1 to 18.

III. RESULTS AND DISCUSSION

X-ray Fluorescence

XRF analysis result on the steel slag is presented in Table 1. The result shows that the steel slag is a heterogeneous material whose main components are iron oxides, elemental iron, manganese oxide and calcium compounds. Of particular notice is the percentage composition of CaO, which was determined to be 7.7254 % by weight.

Table 1: XRF Result of Steel Slag Sample

Elements	*Conc Value*	*Unit*
K_2O	2.3682	wt.%
CaO	7.7254	wt.%
TiO_2	1.8562	wt.%
MnO	15.517	wt.%
Fe	91.968	wt.%
V	997	ppm
Cr	2.0811	wt.%
Ni	341	ppm
Cu	1086	ppm
Zn	4986	ppm
Zr	757	ppm
Nb	388	ppm

Natural Soil

The summary of the result of the geotechnical properties of the natural soil is presented in Table 2. The natural moisture content of the soil was found to be 14.3 %.

Table 2: Geotechnical Properties of Natural Soil

Natural Moisture Content (%)	14.3
Specific Gravity	2.65
Liquid Limit (%)	40.8
Plastic Limit (%)	26.5
Plasticity Index (%)	14.3
AASHTO Soil Classification System	A-7-6
Group Index	5
Unified Soil Classification System	CL
Maximum Dry Unit weight (kN/m^3)	18.2
Optimum Moisture Content (%)	17.5
Unconfined Compressive Strength (kN/m^2)	104
Unsoaked CBR (%)	51
Soaked CBR (%)	49
Swell Potential (%)	0.2
Permeability (cm/s)	1.68 x 10^{-4}
Colour	Brown

Sieve Analysis

The particle size distribution of the lateritic soil sample is presented in Figure 1. Figure 1 indicate that about half of the particles of the soil sample are silt and clay-size minerals. [11] specified the range of silt and clay contents in lateritic soils to be from 12 % to 82 %. That of this soil sample lies nearly half way within this specified range. Figure 1 also shows that about 5 % gravel and 45 % sand were present in the soil sample.

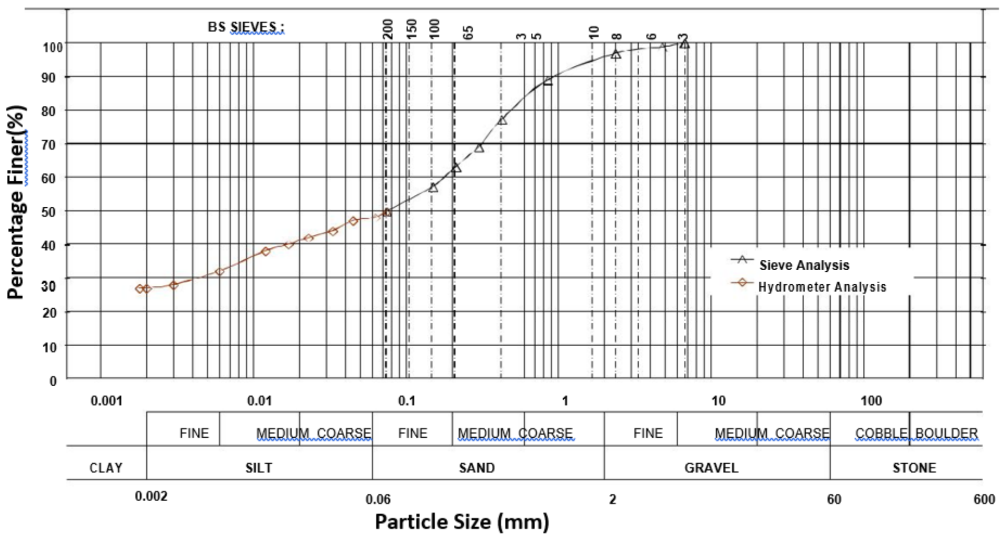

Figure 1: Particle size distribution of soil

Specific Gravity

Variation of the specific gravity test for the soil sample with changes in steel slag content is presented in Figure 2.

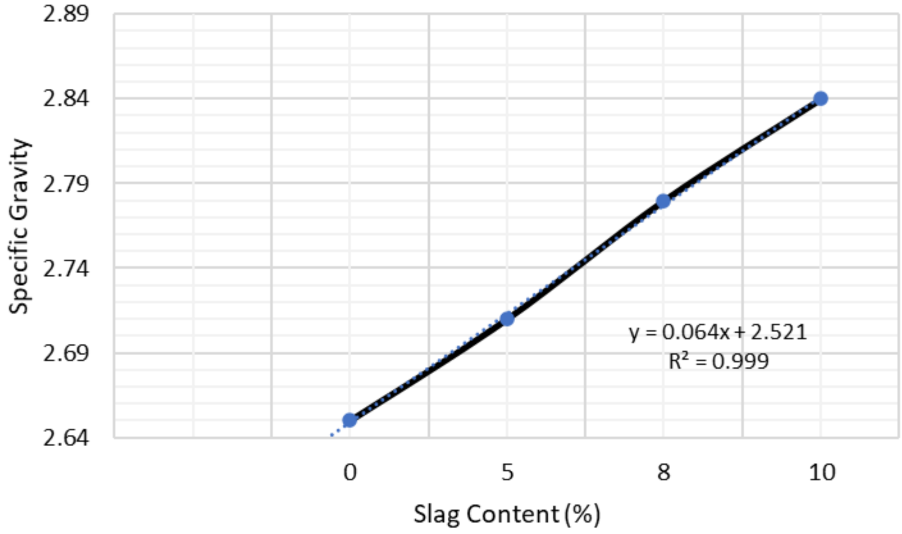

Figure 2: Variation of specific gravity with slag content

Laboratory tests reveal that the average specific gravity of the lateritic soil sample and the ground steel slag sample is 2.65 and 3.58, respectively. The specific gravity of the lateritic soil is within the range of 2.6 and 3.4, which was reported by [7] for lateritic soils. Also, that of steel slag lies within the range of 3.2 and 3.6 reported by [12]. Test results show that at 5%, 8% and 10% steel slag content the specific gravity is 2.71, 2.78 and 2.84, respectively as shown in Figure 2. A higher steel slag content expectedly increased the specific gravity of the mixture. This is also due to the chemical composition of the mixture, which is higher in iron oxide with increasing steel slag content.

Atterberg Limits

This test was performed to determine the liquid and plastic limits, and the plasticity index of the lateritic soil sample. This was done to characterize its condition by water content. The liquid limit tests were repeated twice and an average was taken and used. With progressive increment in percentage of steel slag content in the lateritic soil, the liquid limit, plastic limit and plasticity index all progressively decreased. This decrease can be seen for each of liquid limit, plastic limit and plasticity index in Figures 3, 4 and 5, respectively. The figures also show generated linear (model) equations for the variation of each of these parameters with the slag content in the lateritic soil.

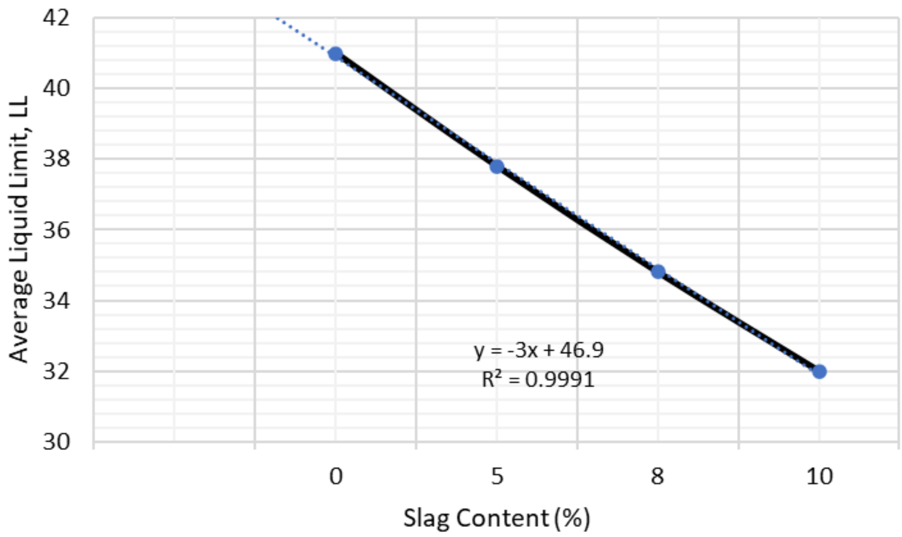

Figure 3: Variation of average liquid limit with slag content

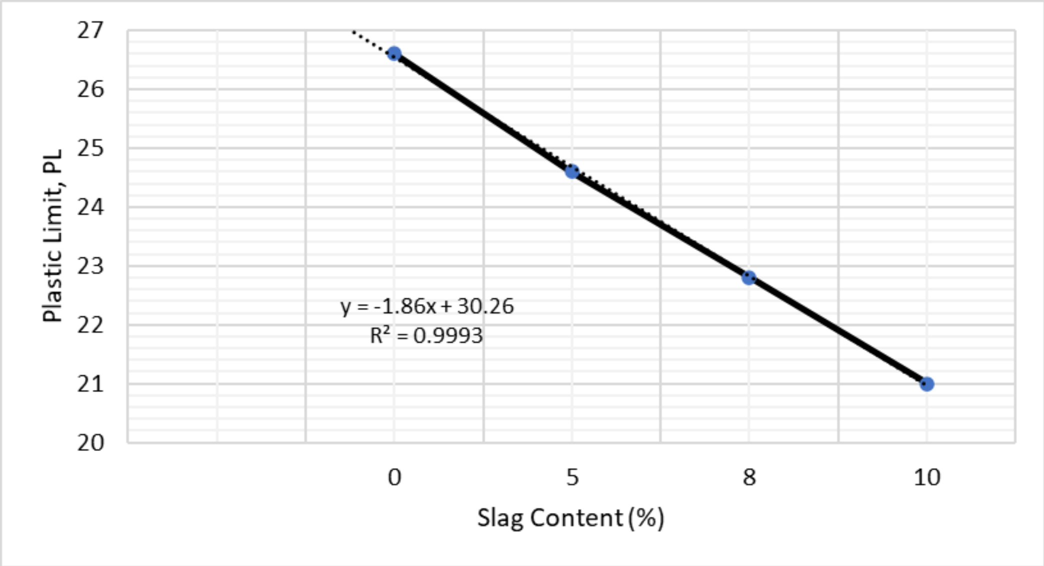

Figure 4: Variation of plastic limit with slag content

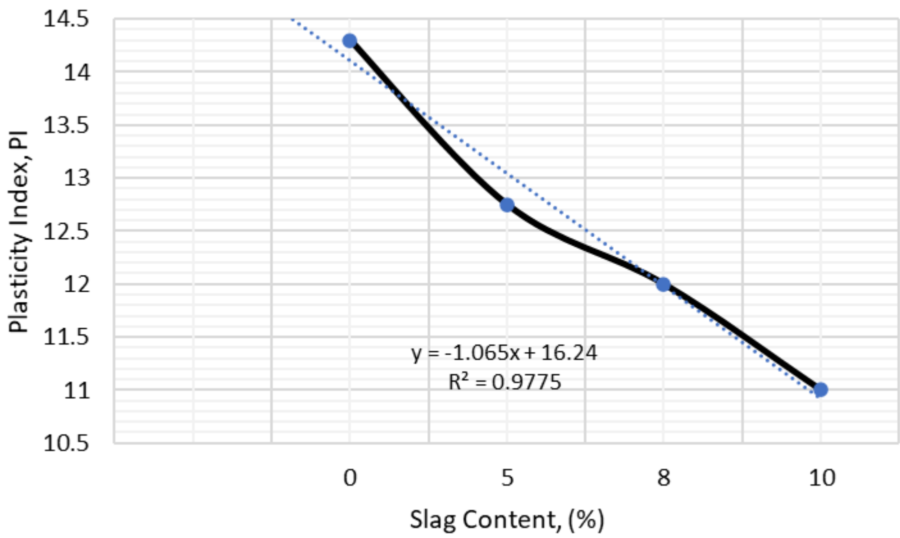

Figure 5: Variation of plasticity index with slag content

These decreases in liquid and plastic limits and plasticity index with increases in slag content is due to the progressive increase in the amount of the silt-size particles in the mixture due to flocculation and agglomeration of clay and the consequent reduction of the amount of clay-size particles in the lateritic soil. This clusters of clay minerals in the soil and clay-size minerals in the slag due to ion exchange at the surface of the soil particles resulted in more stable silt-sand-like structures, making the mixture more workable.

Compaction Characteristics

The change in optimum moisture content (OMC) and maximum dry unit weight with slag content can be seen in Figures 6 and 7, respectively.

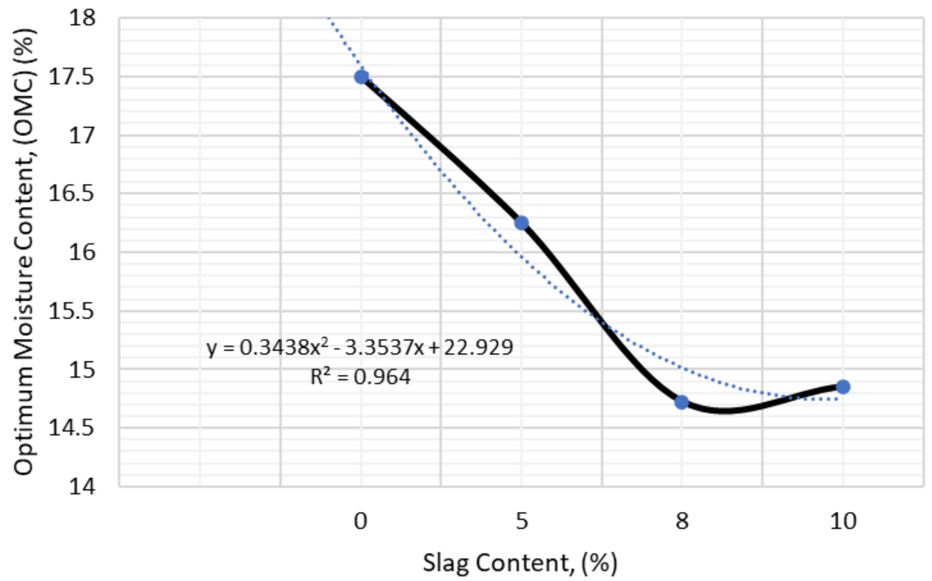

Figure 6: Variation of Optimum Moisture Content (OMC) with slag content

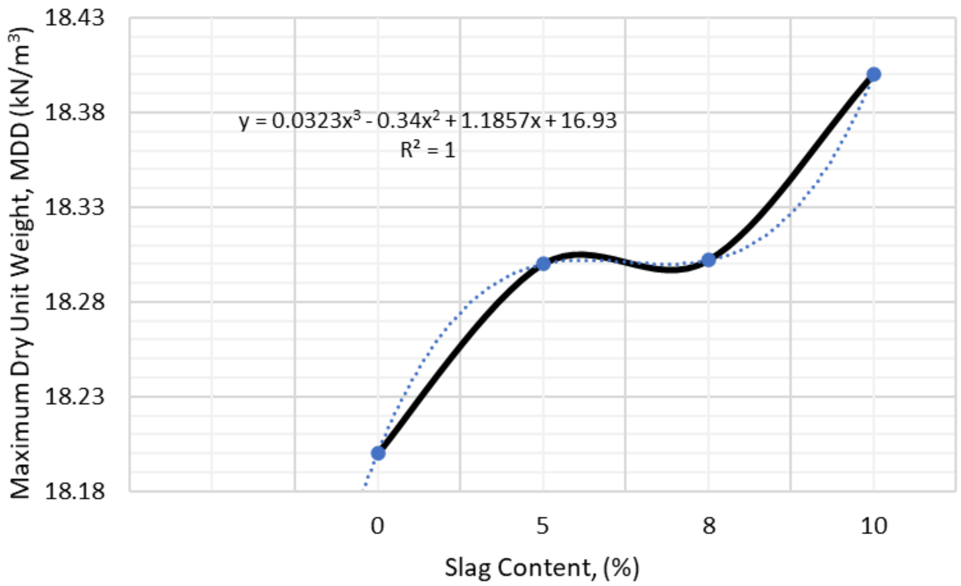

Figure 7: Variation of Maximum Dry Density (MDD) with slag content

The maximum dry unit weight of soil-slag mixtures, expectedly, increased with higher steel slag contents, although there was slight stability between 5 and 8 % slag contents while optimum moisture content decreased as the amount of steel slag in the mixture increased from 0 to 8 % before a slight increase for the 10 % slag content.

The increase in maximum dry unit weight with increasing steel slag content is expected because when lateritic soil with specific gravity of 2.65 is mixed with steel slag with specific gravity of 3.58, the tendency is that the mixture tends to increase its dry unit weight. On the other hand, the decrease in optimum moisture content with higher steel slag content from 0 to 8 % before the slight increase was contrary to expectation. It was expected that unhydrated lime content in the steel, however small, will require extra water for its hydration, thereby increasing the optimum moisture content with higher steel slag content. This deviation might be attributed to the effect of the prior exposure of the steel slag to weather for about a year and the agglomeration (clumping-together) of clay particles, considering the fact that the coarser the grain of a soil the lesser the water it requires to reach optimum.

California Bearing Ratio

The change in unsoaked CBR value with slag content can easily be seen in Figure 8. Figure 8 indicate that the unsoaked CBR value for the soil-slag mixture progressively increased from 51 % for the 0 % steel slag content to 91% for 8 % slag addition before a decrease to 79 % for 10 % steel slag content. Similarly, the change in soaked CBR value and swell potential with slag content can easily be seen in Figures 9 and 10, respectively.

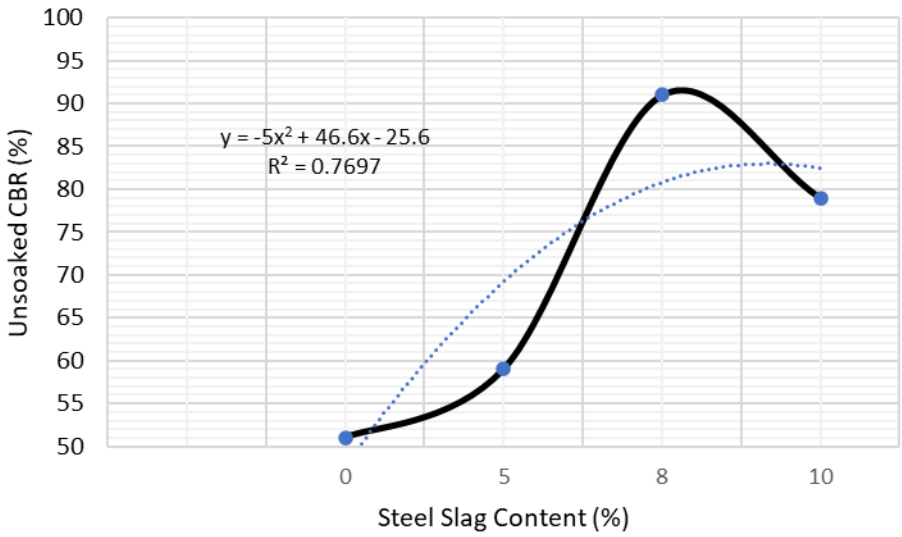

Figure 8: Variation of Unsoaked CBR (%) with Steel Slag Content (%)

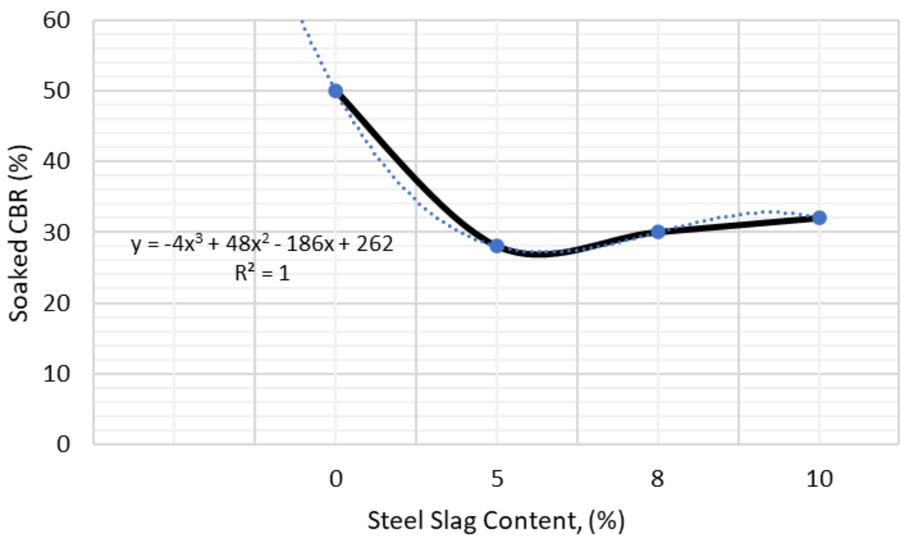

Figure 9: Variation of soaked CBR with slag content

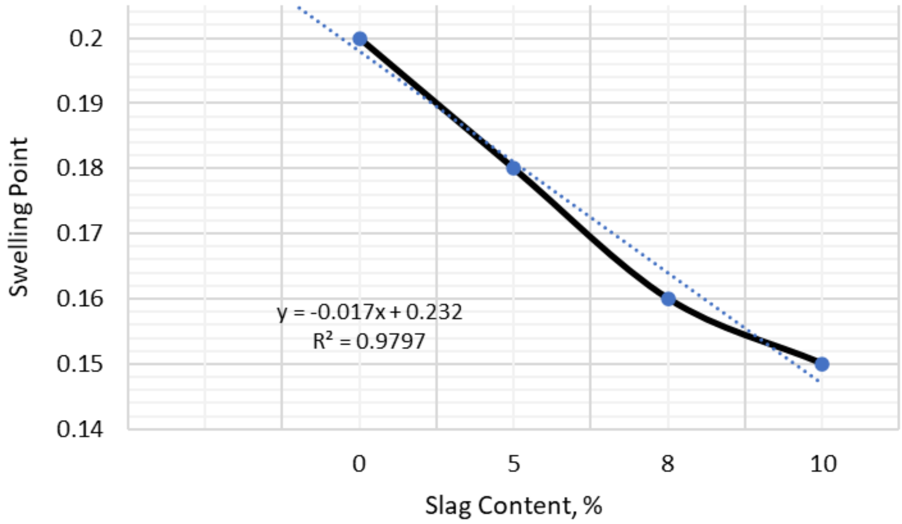

Figure 10: Variation of Swelling point with slag content

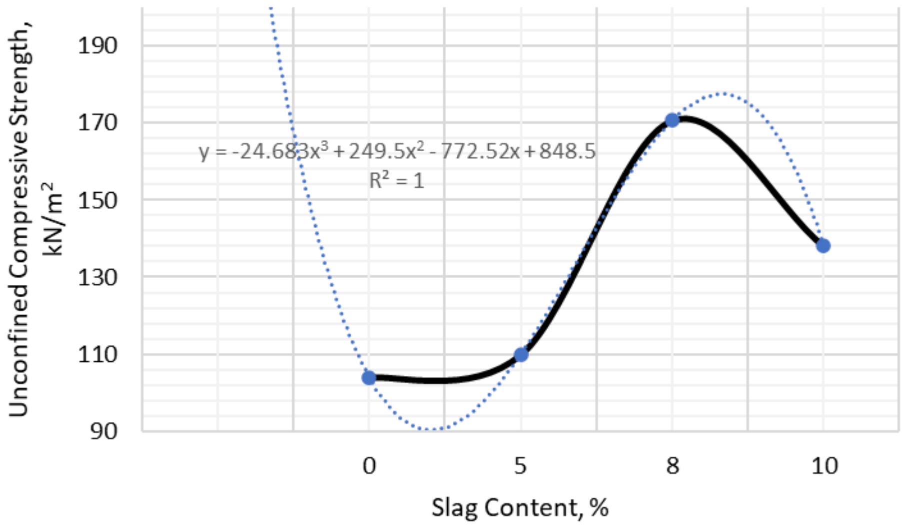

Figure 11: Variation of Unconfined Compressive Strength, kN/m^2 with slag content

Figure 11 shows that the unconfined compressive strength increased with increasing steel slag content from 104.0 kN/m^2 for 0% slag content to 170.7 kN/m^2 for 8% slag content, before decreasing.

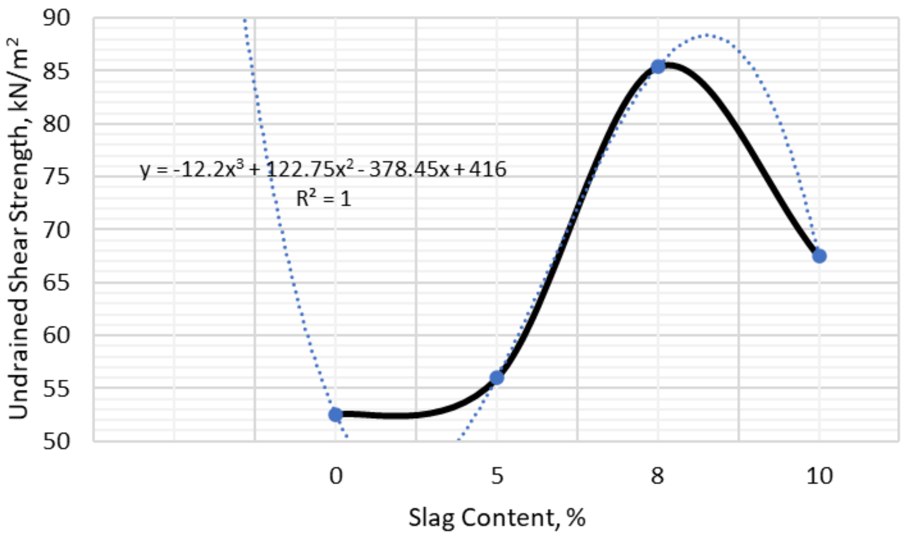

Figure 12: Variation of undrained shear strength with slag content

The undrained shear strength responded in a similar way with the unconfined compressive strength with increasing percentage of slag content (Figure 12). The significant increment of the unconfined compressive strength and undrained shear strength from 104.0 kN/m^2 and 52.0 kN/m^2 to 170.7 kN/m^2 and 85.4 kN/m^2, respectively could probably be due to ion exchange at the surface of clay particles as the Ca^{2+} in the stabilizer reacted with the lower valence metallic ions in the clay microstructure, which resulted in agglomeration and flocculation of the clay particles. The subsequent reduction in the unconfined compressive strength and undrained shear strength to 135.5 kN/m^2 and 67.8 kN/m^2 for 10 % slag content also suggests that the limit of influence of the solidification effect had been reached. This could be partly due to excess of lower valence cations that could not be neutralized with the available higher valence cations.

Optimal Stabilization

Peak value for the uncured strength (unsoaked CBR, unconfined compressive strength and undrained shear strength) of soil was recorded at 8 % steel slag content. Table 3 presents some of the results obtained from the treatment of the soil at OSC and compares them with requirements of [13].

Table 3: Some Geotechnical Properties at Optimal Stabilization

Properties	At OSC	*Subgrade Requirement	*Sub-base Requirement	*Base Course Requirement
Liquid Limit (%)	34	≤ 80	≤ 35	≤ 35
Plasticity Index (%)	12	≤ 55	≤ 12	≤ 12
Soaked CBR (%)	29	N. A.	≥30	≥80

* Nigerian General Specifications (1997)

IV. CONCLUSION

Test results generally indicated that the addition of ground steel slag reduced the plasticity of lateritic soil and thereby improved its workability and reduced its moisture-holding capacity and swell potential. The study also revealed that the maximum dry unit weight of the soil increased with increasing steel slag content while optimum moisture content decreased as the amount of steel slag in the mixture increased from 0 to 8 %. The uncured strength of the soil increased with increasing steel slag content until after 8 % steel slag. Consequently, the optimum steel slag content was determined to be 8 %, based on strength criterion. Therefore, 8 % optimal stabilization of the A-7-6 soil effectively reduced the plasticity of the natural soil to meet the requirement for use as either subgrade, sub-base and base course materials but reduced the soaked CBR value of the natural soil.

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