**American Journal of Engineering Research (AJER)**
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-6, pp-20-27
www.ajer.org
Research Paper Open Access

# Effect of Steel Slag on Engineering Properties of Lateritic Soil

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***Abstract:*** *This project investigated the effect of steel slag on engineering properties of lateritic soil. The samples were subjected to laboratory tests. The tests conducted on both the natural sample and the improved samples are: grain size distribution, Atterbergs limits, compaction, California Bearing Ratio (CBR) and Unconfined Compressive Strength.The study shows that the optimum moisture content (OMC) of lateritic soil sample stabilized with steel slag decreases as compared to the natural sample. The study also reveals that the increase in steel slag causes a decrease in consistency properties. This in turn reduces the plasticity index and shrinkage limit of the soil sample compared to natural soil sample. The result of the California Bearing Ratio (CBR) shows an increase in the CBR due to increase in the percentage of steel slag compared to natural soil. The research also shows an increase in the Unconfined Compressive Strength as the content of steel slag increase.Conclusively,addition of steel slag to the lateritic soil notably improves its geotechnical properties.*

***Keywords:*** *steel slag, lateritic soil, engineering properties, CBR, geotechnical*.

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Date of Submission: 21-05-2020 Date of acceptance: 07-06-2020

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## I. INTRODUCTION

Various pavement distresses have been observed on the road due to use of poor materials for road construction. Hence the need to discover various ways of improving the properties and suitability of laterite for road construction. The sub-grade layer being a very important layer in road construction needs proper design and use of high quality material. Stabilization using cement and lime has proved to be effective over the years. However due to the high prices of stabilizers, other methods need to be in co-operated so as to reduce the cost of stabilization and hence reducing the cost of road construction and reducing the hazard of disposing steel slag.

Soil stabilization is the modification of soils to enhance their properties and stability. Stabilization can increase the shear strength of a soil and control the shrink-swell property of a soil, thus improving the load bearing capacity of a subgrade to support pavement and foundation. Stabilization can be used to treat a wide range of sub-grade materials, varying from expansive soil to granular materials. This process is accomplished using a wide variety of additives, such as fly ash, Portland cement, steel slag (Vega*et al*., 2018; Oluwasola*et al.*, 2015).

Steel slag is a by-product produced during the conversion of iron ore or scrap iron to steel.With rapid growth of steel production over the world, steel slag, as a by-product of steel production, has now been produced quite fast. Now the total amount of steel slag produced in China is around 1 billion tons. However, such a waste of steel slag could lead to not only the loss of money but also lots of environmental pollution (Cheng*et al.*, 2012; Yi *et al*., 2012; Sheen *et al*., 2020).

During the last decade, the global demand for indigenous laterite soil has continued to increase. This growing demand has generated interest in the use of red tropical soils for road materials especially in the developing countries. There have been several cases of pavement failures due to poor laterite materials. Hence, it calls for improvement of the engineering properties of laterite soil to improve compressive strength and durability. The red soil which is abundant in Nigeria gives unique challenges .The use of this as a road material is encouraged by several advantages such as, the relative cheapness of this soil, the vast abundance of this soil, reduction in the foreign exchanges used in buying imported materials and it enhances high rate of road construction. The increasing growth in population and the corresponding increase in demand for road construction in Nigeria during the last two decades have generated increased interest in the ways by which the strength properties of laterite can be improved (Akinwumi, 2014).

By utilizing steel slag to stabilize lateritic soil, environmental hazard due to their disposal is avoided and thus an economically efficient method of lateritic soil stabilization can be achieved. This study is aimed at determining the geotechnical properties and evaluation of steel slag in stabilizing lateritic soil with a view to determine their suitability. (Haldankar,2016; Oluwasola *et al*., 2016a; Roychand et al., 2020)

## II. METHODOLOGY

### 2.1 Sample Collection

The lateritic sample was collected from Owode-Ede, Ede, Osun State and the steel slag sample was collected from Ife Iron and Steel Nig. Ltd., Ile Ife, Osun State of Nigeria in large quantity. Laboratory tests carried out include: Sieve analysis, Atterberg test (liquid limit test, plastic limit test, and shrinkage test), compaction test, Califonia bearing ratio test and unconfined compressive test.

### 2.2 Sieve Analysis Test

A sieve analyses or graduation test is a method commonly used in civil engineering to assess the particle size distribution or graduation of a granular material by allowing the material to pass through a series of sieve of progressively smaller mesh size (openings) and weighing the amount of material that retained on each sieve as a fraction of the whole mass. The percentage retained on each sieve can be obtained using equation 1.The particle size distribution is often of critical importance to the way the material will perform when used.

$$\%\ \text{Retained} = \frac{\text{Weight of sample retained}}{\text{Total weight of sample}} \times 100\% \qquad (1)$$

### 2.3 Liquid limit

Approximately 200g of lateritic soil passing through 0.425mm sieve was measured accurately from the sample by weighing balance and mixed on a smooth glass with small amount of water by spatula until it appears as a smooth uniform paste having consistency that required 25-45, blows of casagrande cup. The paste was filled up the casagrande cup using spatula and leveled up, the leveled paste inside the cup was then cut from the middle by grooving tool to make groove at the centre which divided the paste into two equal halves. The cup was dropped from a height of about 10mm by turning the crank at the rate of two revolution per seconds until the two halves come in contact and the required number of blows to cause the groove closed was recorded. The representative slice of the sample was collected into a moisture can of determined weight and weighed with the sample and then placed inside an oven of $105^0$c for 24hrs to determine its moisture content of the soil sample. The remaining was remixed and the above procedure was repeated for the remaining three trials so as to determine the average moisture content of the soil sample. The experiment was performed with lateritic soil containing 0%, 2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18% and 20% of steel slag.

### 2.4 Plastic limit

The remaining empty moisture cans were weighed, and recorded with respective weights and numbered. The remaining 1/4 of the original soil sample was taken and added with water until the soil is at a consistency where it can be rolled without sticking to the hands, the soil was formed into an ellipsoidal mass. The mass was rolled between the palm or the fingers and the glass plate by the use of sufficient pressure to roll the mass into a thread of 3mm diameter. When the diameter of the thread reached the correct diameter, it breaks the thread into several pieces. Knead and reform the pieces into ellipsoidal masses and re-roll them was carried out and the alternate rolling was continue by gathering together, kneading and re-rolling until the thread crumbles under the pressure required for rolling and can no longer be rolled into a 3mm diameter thread. The threads were gathered together and placed into moisture can. Each moisture can was weighed with the threads in its and was recorded and then placed inside the oven for 24hrs. The experiment was performed with lateritic soil containing 0%, 2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18% and 20% of steel slag.

### 2.5 Shrinkage limit test

An aluminum shrinkage dish was coated with petroleum jelly to prevent the soil from sticking to the dish and forming cracks when drying. The dish was filled in three layers by placing approximately one-third of the amount of wet soil to fill the dish and tapping the dish on a firm base. This step was repeated with the second and third layers and the soil was smooth across the top of the dish with a spatula. The mass of the soil and dish was recorded. The dish and soil were placed in oven for at least 24hours until the soil turned a lighter color and the soil was dried at a constant mass. The dried dish was removed from the oven and the shrinkage was determined by measured with ruler. The experiment was performed with lateritic soil containing 0%, 2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18% and 20% of steel slag

**2.6 Compaction Test**

Soil sample of 5Kg was taken and water of the 6% of the sample (300ml) was added and mixed thoroughly. The base plate was attached to the mould after determined the weight of the mould. Then the moist soil in the mould was compacted in three equal layers, each layer being given 25 blows from the 2.5Kg rammer dropped from a height of 310 mm above the soil. The extension is removed and the compacted soil is leveled off carefully to the top of the mould by means of a straight edge. Then the mould and soil is weighed. The soil was removed from the mould and a small soil sample was taken from both side (on the top and bottom) to determine water content of the soil sample. The procedure was repeated after continuous addition of 150ml of water to the soil until the weight of soil and mould was dropped.

**2.7 California Bearing Ratio Test**

Soil sample of 8kg was taken and the optimum water content determined from compaction test was added and mixed thoroughly. The weight of the mould was determined and the base plate was attached to it. After cleaning the mould and oiled for easy remover of the sample from the mould. The moist soil was compacted in five layers; each layer given 27 evenly distributed blows using rammer of weight 4.5kg.

The extension is removed and the compacted soil is leveled up carefully to the top of the mould by means of a straight edge after removing the collar. The base plate was also removed and the mould was inverted. Then it was climbed to the CBR machine. Then the normal load was applied and CBR values were recorded. The procedure was repeated for the other percentage of steel slag. The penetration and load value were taken and recorded.

**2.8 Unconfined Compressive Strength Test**

A re-molded compacted specimen was prepared of predetermined water content in a large mold and then cut using the sampling tube, the specimen were weighed and representative samples for water content determination were kept. The specimen was placed on the bottom plate of the loading device and the upper plate was adjusted to make contact with the specimen and the deformation and proving ring dials were adjusted to zero and the axial load was applied with a strain rate of 0.5% to 2% per minute and then the force and deformation readings at suitable interval were recorded with closer spacing, during the initial stages of the test.The load was applied until an axial strength of 20% is reached and the failure pattern was sketched and when the specimen failed, the angle of the failure surface with the horizontal was measured and then water content of the representative sample from the failure zones was taken.

## III. RESULTS AND DISCUSSION

**3.1.Sieve Analysis Result of Lateritic Soil**

The index properties of the natural soil show that it is an A-2-7 soil according to AASHTO classification system. The soil has a liquid limit value of 50%, plastic limit of 26.79%, plasticity index of 23.21% and linear shrinkage of 9.64% with 0.80% of the soilparticles passing the BS No. 200 sieve (0.075 mm apertures) and its particle size distribution curve is shown in Fig.1.

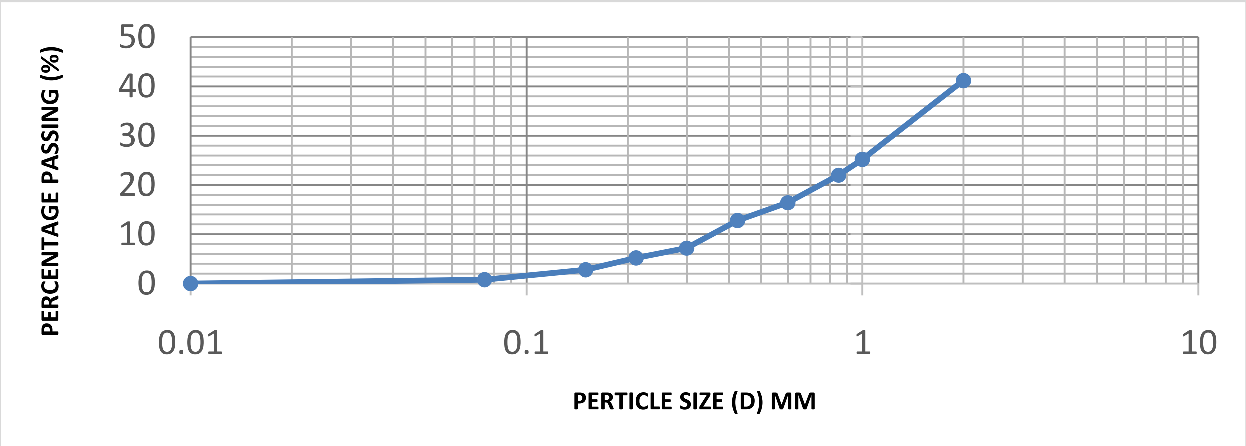


**Fig.1: Sieve Analysis of Lateritic Soil**

**3.2. Sieve Analysis Result of Steel Slag**
The slag has 3.60% of the soilparticles passing the BS No. 200 sieve (0.075 mm apertures). Its particle size distribution curve is shown in Fig.2.

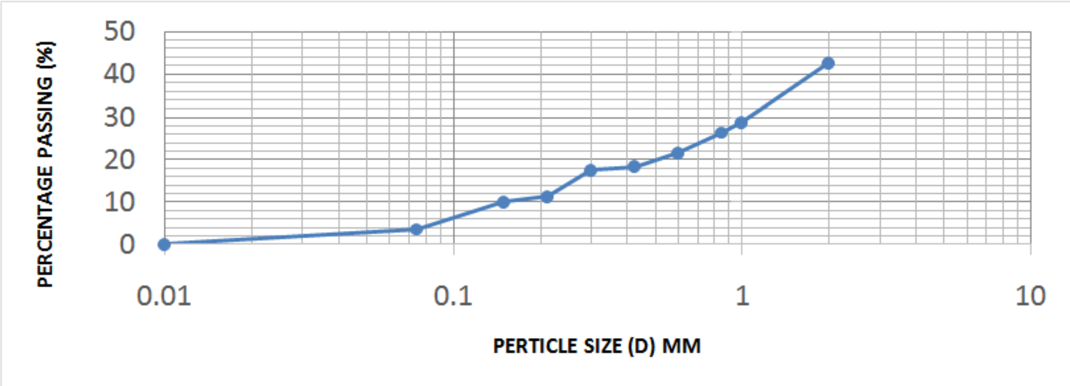


**Fig.2: Sieve Analysis for Steel Slag**

**3.3 Effect of Steel Slag on Maximum Dry Density and Optimum Moisture Content of Lateritic Soil**

The variations of compaction parameters: Maximum Dry Density (MDD) and Optimum moisture content (OMC) with different percentages of steel slag added to the lateritic soil is presented in Figs. 3a and 3b. It is observed that as MDD increases, OMC decreases and vice-versa. Significantly, it was observed that the MDD increases with the addition of steel slag upto 4% while OMC decreases and the MDD decreases from 6% upto 10% of additives at which OMC increases. The MDD later increases from 12% upto the last additives percentage while the OMC decreases. The decrease in MDD at the point of which it decreases are relatively high compare to the natural state of lateritic soil.

The increase in MDD of treated soil sample occurred since steel slag has greater specific gravity compare to lateritic soil. Moreover, the exposure of steel slag to local weather for month (more than a year) resulted in the hydration of the lime content of the steel slag. This has led to the reduction of OMC of the treated sample with increase in steel slag content. This finding is in conformity with (Heaton *et al.*, 2016; Roslan*et al.*, 2020; Oluwasola*et al.*, 2016b).

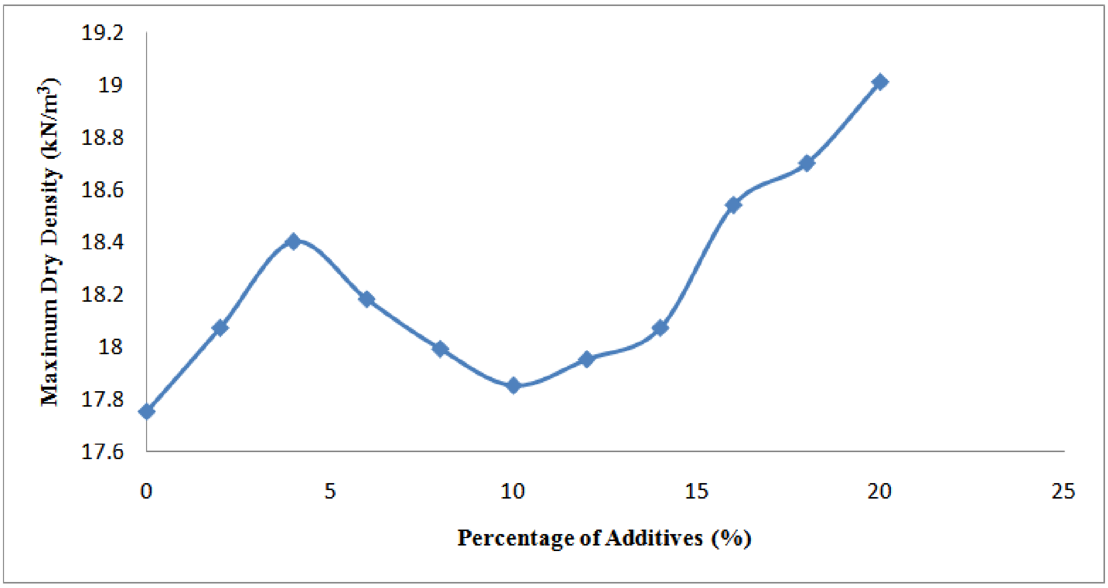


**Fig. 3a: Maximum Dry Density of lateritic soil with various percentage of steel slag**

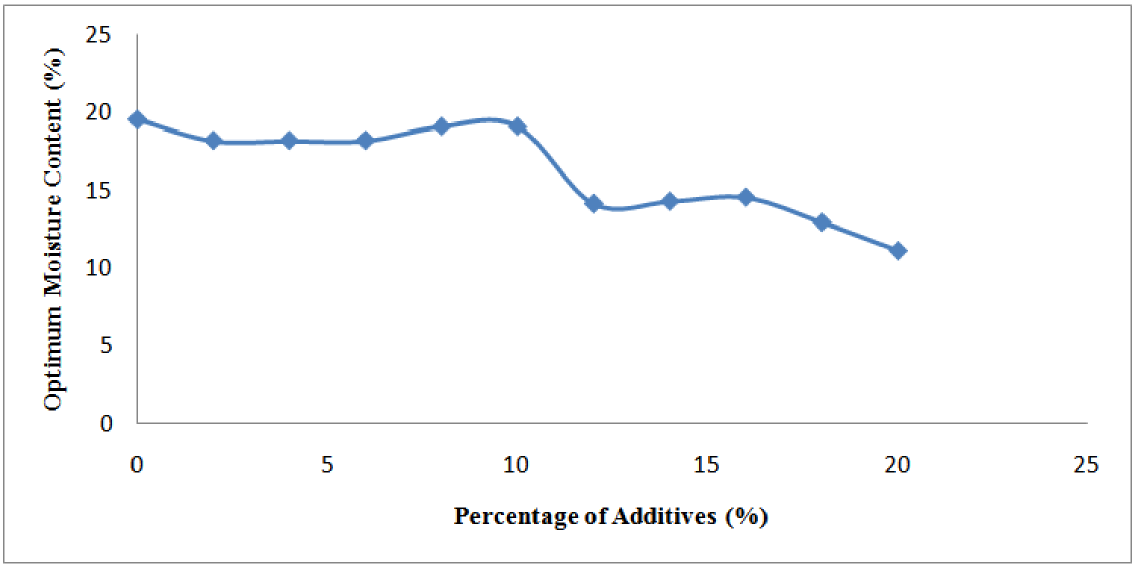


**Fig. 3b: Optimum Moisture Content of lateritic soil with various percentage of steel slag**

### 3.4. Effect of steel slag on California Bearing Ratio of Lateritic soil

The Figs.4a to 4cpresent the result of CBR test for the lateritic soil with 0%to 20 % at interval of 2% and also shown the relationship between resistance and the penetration values. By consideringthe 2.5mmand5.0mmpenetration for the soil treated with steel slag, it is observed from 0% to 10% of steel slag that CBR value of 5.0mm is greater than that of 2.5mm, having observed the result, it has been noticed that CBR values for 2.5mm is greater than 5.0mm penetration value form 12% to 20% 0f steel slag additive. The increase in the CBR values with increase in percentage of steel slag content is due to increase Maximum Dry Density and reduction in Optimum Moisture Content(Shreyas,2017; Yi *et al*., 2012).

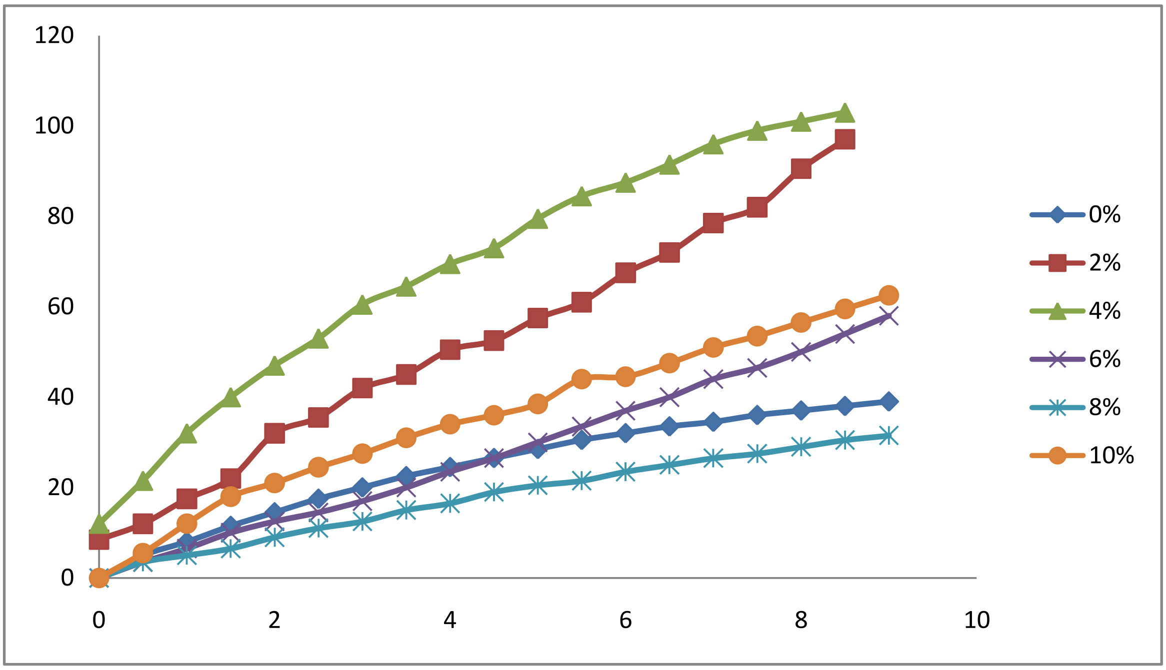


**Fig. 4a: California bearing ratio result from 0% to 10% of Steel Slag**

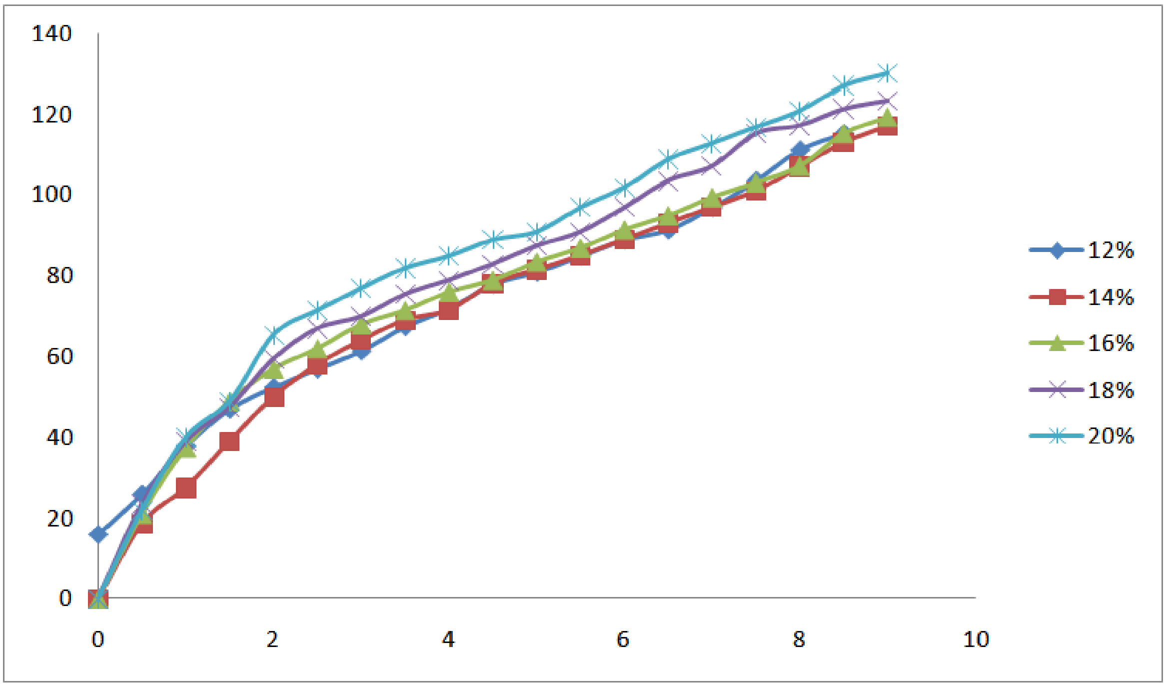


**Fig. 4b: California bearing ratio result from 12% to 20% of Steel Slag**

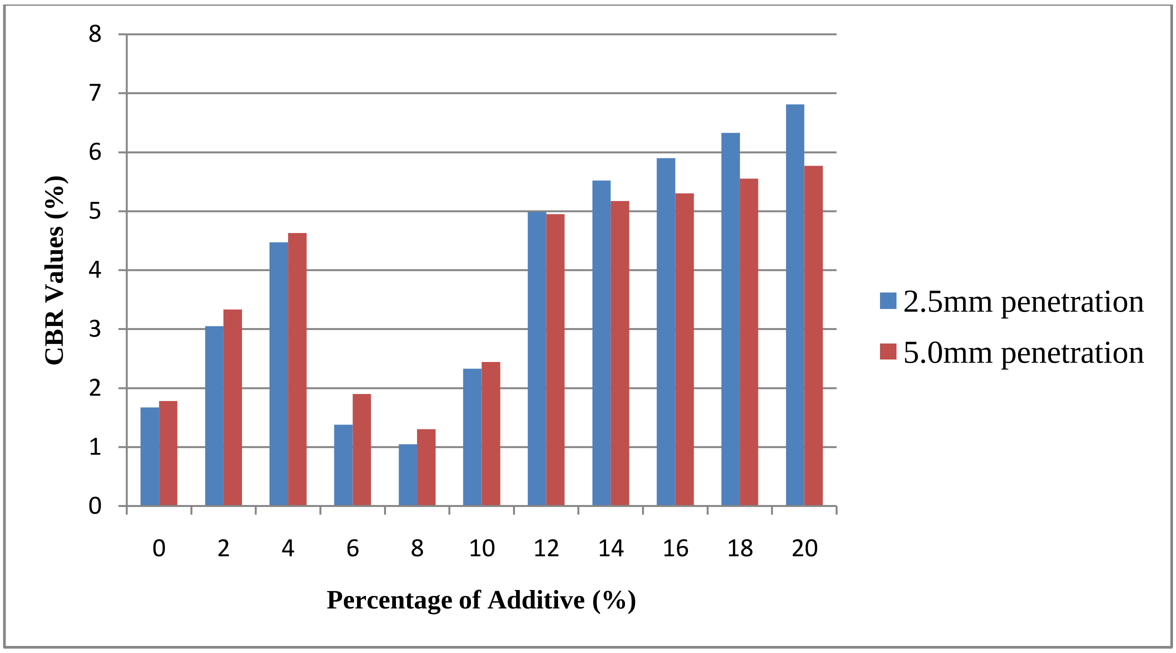


**Fig. 4c:California Bearing Ratio values at 2.5mm and 5mm penetration from 0% to 20% of Steel Slag**

### 3.5. Effect of Steel Slag Atterberg limit of lateritic Sample

The variation in liquid limit and plastic limit of the lateritic soil stabilized with steel slag with percentages of 0-20 at interval of 2% is shownin Table 1. The plasticity index is deduced from plastic limit and liquid limit and it was observed to be increased at 2%, 8% and 10% of the additives of steel slag while it decreases at 4%, 6% and subsequently reduces when the steel slag additives reached 12% upto 20% of the treatment. The decrease in the plasticity index with increase in the steel slag content is due to size of particle in the mixture (steel slag is well graded) leading to reduction in amount of clay size particle in the soil particle (Akinwumi, 2014). Having study the result, the effective point of steel slag on the treated lateritic soil ranges from 12% to 20% of the steel slag additive.

**Table 1:** Atterberg limit properties of lateritic soil stabilized with steel slag

| Percentage of steel slag (%) | Liquid limit (%) | Plastic limit (%) | Shrinkage limit (%) |
|---|---|---|---|
| 0 | 50.00 | 26.79 | 9.64 |
| 2 | 48.54 | 25.83 | 9.14 |
| 4 | 47.23 | 24.42 | 8.93 |
| 6 | 45.87 | 23.52 | 8.50 |
| 8 | 44.12 | 22.75 | 8.50 |
| 10 | 42.65 | 20.17 | 8.28 |
| 12 | 40.22 | 18.42 | 7.50 |
| 14 | 42.34 | 26.50 | 7.86 |
| 16 | 43.65 | 26.75 | 8.57 |
| 18 | 45.90 | 28.67 | 9.28 |
| 20 | 49.45 | 34.83 | 9.50 |

### 3.6. Effect of Steel Slag on Unconfined Compression Test of Lateritic soil

The variation in the unconfined compressive strength with steel slag content is shown in Table 2. It is observed that the unconfined compressive strength increased with increasing steel slag content till it reaches 20% of the additive before it decreases. The increase in unconfined compressive strength is due to increase in maximum dry density and reduction of optimum moisture content. The decrease at 20% additive of steel slag content shows that the limit effect of the solidification has been reached. This is in agreement with (Mortz and Geiseder 2001; Oluwasola*et al.*, 2018) who says the increase in the strength was explained by carbonate hardening due to fine oxides of calcium that present in the slag material.

**Table 2**: Unconfined compressive strength of lateritic soil stabilized with steel slag

| Percentage of steel slag (%) | Unconfined compressive strength (kPa) |
|---|---|
| 0 | 151.6 |
| 2 | 157.0 |
| 4 | 164.6 |
| 6 | 172.4 |
| 8 | 180.8 |
| 10 | 191.2 |
| 12 | 208.8 |
| 14 | 216.4 |
| 16 | 212.7 |
| 18 | 208.2 |
| 20 | 205.4 |

## IV. CONCLUSION

This study has concentrated on the effect of steel slag on the engineering properties of lateritic soil. Based onthe study, the following conclusions were drawn;

Stabilizing lateritic soil with steel slag notably improved its geotechnical properties, causing a decrease in Optimum Moisture Content of the soil which is advantageous in decreasing quantity of water required for compaction. The decrease in OMC is due to the exposure of steel slag to local weather for more than one year which resulted in the hydration of the lime content present in steel slag. The study also shows that the Maximum Dry Density keep increasing immediately 12% of the additive is reached up to the last percentage of the additive, this could be due to the higher specific gravity of the steel slag compared with that of lateritic soil. Both the specific gravity and exposure to local weather is of paramount factors that make steel slag effective as modifier.The consistency limits also has significant improvement on the soil sample as the steel slag content increased. The steel slag additive proved very effective 12% as it reduces the plasticity index of the lateritic soil. Mixing of steel slag with the soil sample is also found to improved its CBR and the unconfined compressive strength with increase in steel slag content, this is due to increase in MDD and decrease in OMC which resulted from the higher specific gravity and hydration of lime content present in the steel slag. However, it can be concluded that steel slagproved effective in soil stabilization.

With the result obtained in the investigation, the following recommendations were made:

Steel slag can be used as a soil modifier for use in subgrade since it proved effective in the treated soil sample.Weak soil can be effectively stabilized with steel slag to check its behavior and increase it strength.

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