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EFFECT OF ELECTRIC ARC FURNACE SLAG ON THE ENGINEERING PROPERTIES OF LATERITIC SOIL

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Abstract: It is imperative for geotechnical engineers to harness ways of improving lateritic soil with industrial waste materials in other to satisfy the required highway pavement construction. This work investigated the effect of Electric Arc Furnace Slag (EAFS) on the engineering properties of lateritic soil. Tests to determine the X-Ray Florescence (XRF), X-Ray Diffraction (XRD), grain size analysis and specific gravity of the soil sample and EAFS and the lateritic soil stabilization with varying percentages (0%, 4%, 8%, 12% and 16%) of EAFS using Atterberg limits, Compaction and Shear Strength were carried out. The lateritic soil was classified as A-7-5 (6) and ML according to American Association of State Highway Transportation Official (AASHTO) and Unified soil classification system while the silica-sesquioxide ratio and mineral contents showed that the soil is a lateritic soil as they contain both swelling and non-swelling clay minerals. The stabilized soil sample revealed that EAFS increases the maximum dry density (19.4 KN/m^3 to 23.9 KN/m^3) and decreases the optimum moisture content (14.50% to 9.30%) which could be attributed to the lower affinity of EAFS to water thus, improving the compaction properties. Also, the EAFS has significant effect on the strength parameters of the lateritic soil as it increases the shear strength from 551.11KN/m^2 at virgin state to 974.44KN/m^2 at 16% EAFS. Conclusively, electric arc furnace slag has positive influence on the geotechnical properties of the lateritic soil as it will not only solve the waste disposal problem but can be used as additive to improve the engineering properties of lateritic soil.
Keywords: Electric Arc Furnace Slag, Lateritic soil, Shear Strength, X-Ray Florescence, X-Ray Diffraction

1. INTRODUCTION

Steel slag is a solid waste from steel production. It can be categorized as carbon steel slag and stainless steel slag according to the type of steel, and as pretreatment slag, basic oxygen furnace slag (BOFS), electrical arc furnace slag (EAFS), ladle refining slag (LFS) and casting residue according to the steelmaking process [12]. Steel slag which is a by-product of the conversion of iron to steel, is one of the industrial wastes having a large percentage still being disposed off in landfills which makes it more attractive to reuse and recycle [4]. Approximately 15 to 40% of the 10 - 15 million metric tons of steel slag generated in the United States in 2006 was not utilized and a larger percentage of the 0.35 - 0.45 million metric tons of steel slag estimated by [5] to be generated annually in Nigeria is disposed-off in an environment-unfriendly manner.

Lateritic soils which are products of intense weathering have wider applications in the Nigerian road construction projects. In tropical parts of the world, lateritic soils are used as a road making material and they form the subgrade of most tropical roads. They are used as sub-base and bases for low-cost roads and these carry low to medium traffic. Furthermore, in rural areas of Nigeria, they are used as building material for molding of blocks and plastering [13]. Lateritic soils contribute to the general economy of the tropical and subtropical regions where they are in abundance because, they are widely utilized in civil engineering works as construction materials for roads, houses, landfill for foundations, embankment and dams [3]. Thus, they do not meet existing standard or local requirements for use in engineering projects but generally need improvements to adequately satisfy the required construction purposes.

This lead to the concept of soil stabilisation which is the process of soil alteration to enhance its physical, mechanical, and chemical aspects. Stabilisation raises some of the essential qualities of the soil such as shear strength, volume changes, and bearing capacity. Alternatively, it is a process of mixing soil with a designated amount of additives [7]. The modification of weak soil to improve its engineering performance is used in connection with foundation construction, slope stability, and subgrade construction.

To eliminate the environmental problems and conserve the environment, providing a sustainable road construction method using this by-product should enhance the engineering properties of the lateritic soil.

2. METHODS

Materials

The disturbed soil sample used for this study was collected at an offset of 2.5m from a failed portion along Ede - Osogbo road at latitude 7° 45’ 35” N and longitude: 4° 27’ 38” E. Osun state, Nigeria. The top soil was removed to a depth of 1.5m before the soil sample was taken. Selected sample was collected by manual digging with simple hand implements; shovel and digger and was collected in large-to-medium-sized bags and thereafter transported to the Laboratory, Department of Civil Engineering, Federal Polytechnic Ede,

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Osun State, Nigeria. The soil sample was spread and allowed to air-dry under laboratory conditions. Also, electric arc furnace slag which had been exposed to weather for about 12 months were taken from Prism Steel Mills Nigeria Limited, along Osogbo-Ikirun road, Ikirun, Osun State, Nigeria. The electric arc furnace slag samples were crushed with the aid of Los Angeles abrasion machine to reduce its particle size down to less than 0.425mm in order to allow for Atterberg limit tests to be performed. The electric arc furnace slag at varying percentages (0%, 4%, 8%, 12% and 16% by dry mass of soil) were used to stabilize the soil.

Experimental works

The preliminary and engineering tests carried out were Particle Size Analysis, Specific Gravity, Atterberg limits, Compaction test and Shear Strength test. They were carried out in accordance with procedures described by British Standards Institution [8]. Prior to the preliminary and engineering tests, X – Ray Fluorescence and X-Ray Diffraction tests were conducted to determine the chemical and mineral components of the soil sample and electric arc furnace slag.

3. RESULTS AND DISCUSSION

X-Ray Fluorescence Test

In order to determine the extent of laterization of the soil sample, the percentage concentration of oxides of silica (SiO_2), iron (Fe_2O_3) and aluminum (Al_2O_3) in the soil were determined using the XRF analysis (Table 1). The soil sample is characterized by an appreciable amount of silica, (SiO_2) (24.5%) and sesquioxides Al_2O_3 (1.12%) and Fe_2O_3 (42.1%). The other major oxides concentrations were all lower than 5% and the Loss of Ignition (LOI) is 8.1% which is not up to maximum of 10% as specified by ASTM C618-12 [1]. However, the silica-sesquioxide ratio reveals that the soil sample is a lateritic soil (Equation 1). In the same vein, the oxide composition of EAFS shows an appreciable amount of CaO (38.11%) which is higher than 7.73% as reported by [5]. Also, the amount of chemical composition (SiO_2, Al_2O_3, CaO and Fe_2O_3) of EAFS were found to be 74.39% and belongs to Class N pozzolana according to ASTM C618-12 [1] with tendency to undergoing hydration reaction when mixed with water.

Table 1: XRF Analysis of the Soil Sample and EAFS

Oxides	Percentage of Oxide Content Materials	
	Soil Sample	EAFS
SiO_2	24.50	12.10
Al_2O_3	1.12	4.68
Fe_2O_3	42.10	19.50
MnO	0.49	12.25
CaO	1.62	38.11
MgO	0.64	0.16
K_2O	-	0.40
Na_2O	0.80	0.15
P_2O_5	-	2.20
TiO_2	-	0.29
LOI	8.10	10.16

The silica-sesquioxide ratio is given by;

$$\text{Silica/Sesquioxide Ratio} = \frac{\frac{\%\ \text{of}\ SiO_2}{\text{Molar weight of}\ SiO_2}}{\frac{\%\ \text{of}\ Al_2O_3}{\text{Molar weight of}\ Al_2O_3} + \frac{\%\ \text{of}\ Fe_2O_3}{\text{Molar weight of}\ Fe_2O_3}} \quad (1)$$

where: Molar mass of Si = 28.0g; Molar mass of O = 16.0g; Molar mass of Al = 27.0g; Molar mass of Fe = 56.0g; Molar weight of SiO_2 = 28 + (16 x 2) = 60.0g; Molar weight of Al_2O_3 = (27.0 x 2) + (16 x 3) = 102.0g; Molar weight of Fe_2O_3 = (56.0 x 2) + (16.0 x 3) = 160.0g

X-Ray Diffraction Test

The results of the XRD test on the studied soil sample (Figure 1) shows expanding (chlorite) and non-expanding clay minerals (quartz, magnetite, goethite and kaolinite). The presence of swelling clay mineral is known for their interlayer expansion which happens during their swelling behaviour when they are wet and are prone to large volume change which are related to change in water content. [9] also reported that swelling clays are formed in areas of poor drainage and alkali conditions. This further validates that the studied soil sample is lateritic soil as it contains both swelling and non-swelling clay minerals.

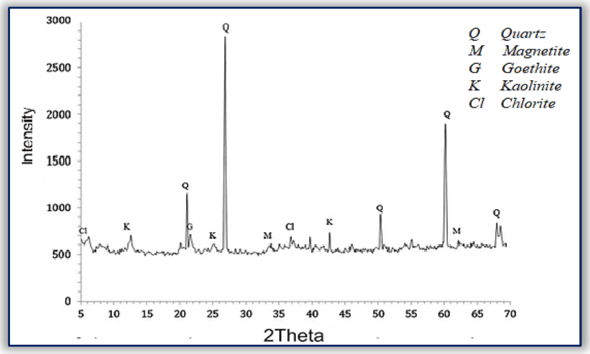

Figure 1: XRD of Lateritic Soil

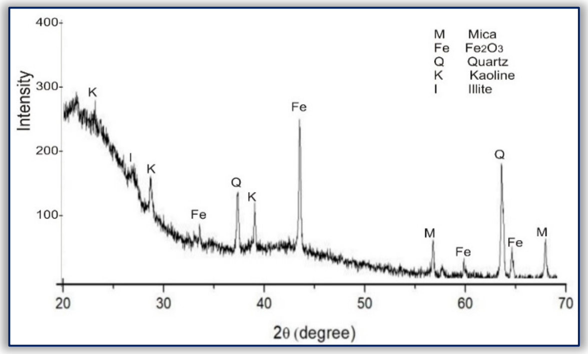

Figure 2: XRD of EAF Slag

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Also, XRD test was conducted on EAFS sample to identify its major components. The main mineral components of EAFS (Figure 2) are Iron Oxide (Fe_2O_3) and quartz (SiO_2), with trace amount of Kaoline ($Al_2O_32SiO_2.2H_2O$), Mica and Alumino–silicate.

Soil Classification

The results obtained for particle size analysis shows that the soil sample is classified as A-7-5(6) and inorganic soil of low to medium plasticity (ML) according to American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS) adjudging the soil as fair to poor highway subgrade material.

Specific Gravity

The specific gravity of the soil sample and EAFS are 2.55 and 2.90 respectively. The soil sample falls within the reported standard report from the Federal Ministry of Works and Housing specification requirement for specific gravity of lateritic soils. Thus, the tested soil sample have low value of specific gravity which could be attributed to the presence of clay minerals. However, the specific gravity of EAFS (2.90) is slightly less than 3.58 as reported by [5] and this is due to sufficient amount of iron oxide in the steel slag.

Atterberg Limit

The results of Atterberg limits determined under different additive contents shows that as percentage of additive increases (0% to 12%), there was a decrease in the capability of water absorption by 19%, which can be seen with the reduction of plasticity index for the stabilised soil (Figure 3). This result agree with the study of [6] that plasticity index were decreased by 21% which can be ascribed to the size of EAFS and chemical reactions between EAFS and soil sample including ion exchange and associated flocculation reactions. This helps in flocculation and aggregation of colloidal clay particles, making them less plastic [14].

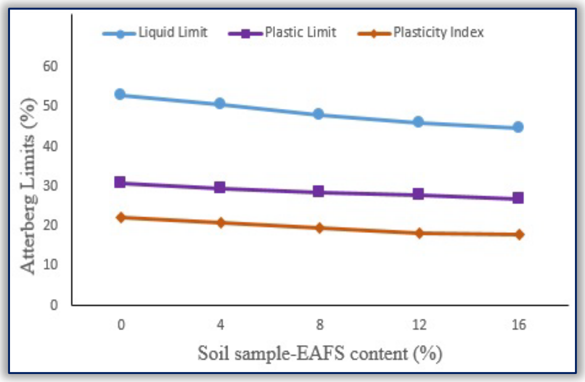

Figure 3: Atterberg Limit Properties of Soil Sample Stabilised with EAFS

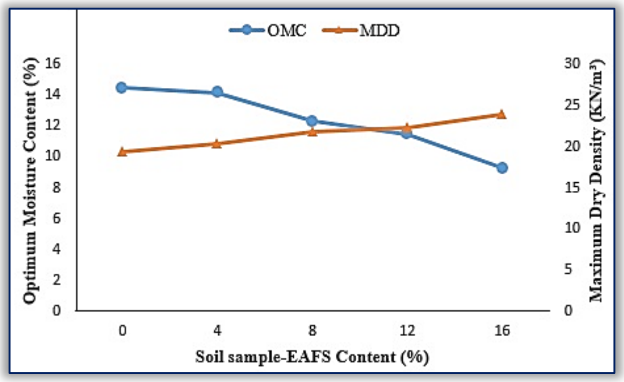

Figure 4: Compaction Properties of Soil Sample Stabilised with EAFS

Compaction Characteristics

The modified Proctor compaction test was carried out for the soil sample and the stabilised soil with various percentages of electric arc furnace slag. According to the results in Figure 4, the Maximum Dry Density (MDD) increases from 18.0KN/m^3 to 23.0KN/m^3 while the Optimum Moisture Content (OMC) decreases from 16.50% to 11.00%. This result shows a percentage increase and decrease of 27.8% and 33.3% for the MDD and OMC respectively. The increase in MDD value with the increase in the EAFS content is associated with the EAFS particles, which are heavy-weight materials because of its high specific gravity compared to the natural soil samples and to the lower affinity of the additive to water as also reported by [2] and [10]. Also, the exposure of EAFS to local weather for one year resulted in the hydration of the lime content of EAFS which led to the reduction of optimum moisture content of the stabilized soil sample with increasing EAFS content as reported by [6]. Also, the reduction in the specific surface of soil particles in the mixture and the stabilised soil samples is an indicator of the soil properties improvement.

Direct Shear Strength

Direct shear strength test was carried out for both natural and stabilised soil sample with various percentages of 0%, 4%, 8%, 12% and 16% EAFS. When the soil sample was subjected to normal stress, analysis showed that the maximum shear stress of the natural soil sample was 551.11KN/m^2 and as the percentage of additive increases, the shear stress increases with the soil sample stabilised at 16% EAFS yielding the maximum shear stress of 974.44KN/m^2 (Figure 5). According to the findings of [11], the low porosity of the soil sample-EAFS as compared to the natural soil sample maximizes the shear strength of the soil sample-EAFS content. Also, the increase in the shear stress is due to the cohesion of the soil sample with the

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surface texture, cubical and angular surface of the EAFS which provides better interlocking and frictional resistance between the EAFS samples.

4. CONCLUSIONS

The following conclusions were drawn from the study based on the tests results:

- The XRF analysis showed that EAFS belongs to class N pozzolana. However, the presence of sesquioxide ($Fe_2O_3 + A1_2O_3$) and SiO_2 shows that soil sample is a lateritic soil. Also, the XRD analysis revealed that the soil sample is characterized by both swelling and non-swelling clay minerals.
- The soil sample was classified as A-7-5 (6) (fair to poor subgrade) and ML (inorganic soil of low to medium plasticity) according to AASHTO and Unified systems of soil classification.
- The soil sample-EAFS content greatly influenced the consistency limits which caused considerable reductions in the liquid limit, plastic limit and plasticity index of the soil sample.
- The stabilization of the soil sample with EAFS increases the MDD and decreases the OMC as the percentage of EAFS increases, thus improving the soil properties and importantly have positive effect on laboratory compaction parameters.
- Using electric arc furnace slag also yielded a useful improvement in the strength characteristics as the additive (EAFS) increases the shear strength of the soil sample with 16% having the maximum strength.
- Base on this study tests, 16% of electric arc furnace slag is the best percentage, which can be recommended to stabilize the lateritic soil as achieved in this study.

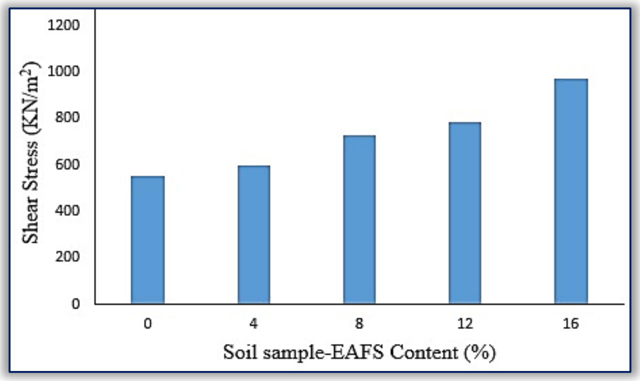

Figure 5: Shear Strength of soil sample stabilized with EAFS

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