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Utilization of Pulverized Steel Slag for Stabilization of Lateritic Sandy Soils

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Abstract: A lateritic soil is classified as sandy clay or (CL) and A-7-6 (5) according to Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) classification system respectively, A lateritic soil is treated with up to 10% pulverized steel slag (an industrial waste product) by dry weight of soil. Elemental and chemical analysis of the steel slag was determined using x-ray fluorescence spectroscopy. Tests were carried out to determine the index properties, compaction characteristics (maximum dry density, MDD and optimum moisture content, OMC), strength characteristics (California bearing ratio, CBR and unconfined compressive strength, UCS) and permeability of the natural and treated soil. Test results show that Atterberg limits (liquid limit, plastic limit and plasticity index) generally decreased, while specific gravity of soil – steel slag mixtures increased with higher steel slag content; MDD and OMC increased and decreased, respectively, with higher steel slag content. Generally, CBR and UCS increased up to 8% steel slag treatment of the soil. Permeability of soil – steel slag mixtures increased with higher steel slag content. Based on laboratory test results, an 8% optimal stabilization of the A-7-6 soil with steel slag satisfactorily meets the Specifications (Roads and Bridges) requirement for sub-grade materials.

Keywords: steel slag, lateritic soil, optimum moisture content, dry density, strength characteristics, optimum slag content

I. INTRODUCTION

Many items discarded by people, organizations and companies have the potential to be reused for their original purposes or for new ones. Reuse allows people to get the most out of the products they buy and saves them money as well. Additionally, reusing products conserves natural resources and saves valuable landfill space. Use of environment-friendly materials in any industry is of paramount importance. Limited waste landfill space, increasing cost of waste disposal in combustion facilities and landfills, depletion of the natural resources, and the need for sustainable development have all amplified the need to reuse the materials that were once regarded as wastes as substitutes for natural resources.

II. AIM AND OBJECTIVES

The aim of this research work was to use steel slag in the stabilization of lateritic soil. The specific objectives of this study include:

Determination of the engineering properties of the lateritic soil samples;

Determination of the index, strength and permeability properties of the lateritic soil-steel slag mixtures; and

Determination of the optimum steel-slag content (OSC) required.

III. SCOPE AND SIGNIFICANCE OF STUDY

The study was limited to the determination of the effect of adding up to 10 % steel slag on the properties of lateritic soil using Modified Proctor compaction energy with respect to compaction characteristics, Atterberg limits, shear strength characteristics and permeability. All tests were carried out in accordance with the procedures outlined in BS 1377(1990) and BS 1924(1990) for the natural and treated soils, respectively. Transforming industrial wastes into valuable materials or resources for further utilization is most desirable (Aguirre et al., 2009). The rate of reuse and recycling of solid wastes/by-products has increased dramatically in the past but considerable amounts are still being disposed to landfills.

Unlike most developed and some developing countries producing steel, India utilizes just a little of the waste it generates during the production of steel. A larger percentage of this waste is disposed off, even, in an environmentally-unfriendly manner (open dumping). Accordingly major environmental concern in the iron and steel industry in India is associated with the management of the industrial wastes generated in their different processes since it is becoming increasingly difficult for safe disposal of these huge volumes. It is common knowledge that steel slag (a major waste generated when producing steel) has long been used in various applications in the construction industry such as aggregates in road construction, railway ballast and hydraulic protection structures.

It is to be noted that, stabilization of soil is employed when it is more economical to overcome a deficiency in a readily available material than to bring in one that fully complies with the requirements of specification for the soil. Lateritic soil is one of the most readily available soil types in India. Thus, the improvement of its engineering properties (high plasticity, poor workability, low strength, high permeability, tendency to retain moisture and high natural moisture content) via its mixing with steel slag will be a double-edge achievement. The cost of treating and disposing the vast number of steel slag stockpiles in the steel producing industry will be reduced while simultaneously reducing the construction cost of borrowing suitable soil materials or using expensive stabilizers.

IV. MATERIALS

A. Steel Slag

Steel slag samples, which had been exposed to weather for about 8 months, were taken from the JSW steel plant, Karnataka (Figure 1). The steel slag samples were crushed to reduce its particle size down to less than 0.425 mm in order to allow for Atterberg limit tests to be performed.

B. Soil

Lateritic soil sample used in this research work was collected, by method of bulk disturbed sampling, from borrow pit behind Jagruthi institute of technology and science, Ibrahimpatnam, Rangareddy district in the state of Telangana. They were collected at a depth not less 0.5 m from the ground, after the removal of topsoil. They were stored and kept dry in bags in the Geotechnics laboratory of the Department of Civil Engineering, Mallareddy Engineering college, Dhulapally, Hyderabad.

Fig 1: Steel Slag Sample used in the experiment

Fig 2: Lateritic Soil Sample

Physical Characteristics such as porosity, density, particle gradation, are affected by the cooling rate of the slag and its chemical composition.

TABLE I: PROPERTIES OF A LATERITIC SOIL

Soil Property	**Value**
Specific Gravity	2.5
Liquid Limit (%)	35.2
Plastic Limit (%)	18.13
Plasticity Index (%)	17.07
Linear Shrinkage	13.08
Maximum Dry Density (kg/m^3)	20 -40
Optimum Moisture Content (%)	13.8
Percent Passing BS No. 200 Sieve	1.5
California Bearing Ratio (CBR)	22.05
AASHTO Classification / USC Classifica	A-2-6(0) / SV
Major Clay Mineral	Illite

TABLE II: TYPICAL MECHANICAL PROPERTIES OF STEEL SLAG

Property	**Value**
Los Angeles Abrasion (ASTM C131), %	20 - 25
Sodium Sulfate Soundness Loss (ASTM C88), %	< 12
Angle of Internal Friction	40 ° -50°
Hardness (measured by Mohr's scale of mineral	6 -7
California Bearing Ratio (CBR), % top size 19 mm	Up to 300

TABLE III : TYPICAL PHYSICAL PROPERTIES OF STEEL SLAG

Property	**Value**
Specific Gravity	3.2 – 3.6
Approx. Dry Unit Weight, Kg/m^3	1600 - 1920
Water Absorption	Up to 3 %

V. METHODOLOGY

Preliminary test (natural moisture content, specific gravity, sieve analysis and Atterberg's limits – Liquid Limit test and Plastic limit test) was 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 them. The effects of steel slag a stabilizing agent on the samples were thereafter determined. The procedures for various tests were carried out in accordance with BS 1377 (1990) and BS 1924 (1990).

C. Details of Experiments

1) Natural Moisture Content: Disturbed lateritic soil samples were collected and stored in a polythene bag, since they should be stored in non-corrodible airtight container and in area that prevents direct contact with sunlight. In the laboratory, representative soil samples were selected from the well mixed soil samples in the polythene bag and its moisture content was determined by oven drying method. The moisture content (ω) of the soil was calculated as a percentage of the ratio of the mass of water to the mass of dry soil.

M_1 = Mass of empty specimen container (g) , M_2 = Mass of empty specimen container plus moist soil (g)

M_3 = Mass of empty specimen container plus dried soil (g)

2) Sieve Analysis: The soil samples were washed through BS No. 200 sieve or 0.075 mm and the material retained was oven dried and sieved by agitating the material through a range of sieves from sieve No.4 or 4.75 mm aperture sieve and downwards while the material passing was turned into a sedimentation cylinder for hydrometer analysis.

3) Specific Gravity: Specific gravity test was carried out both for the slag and the lateritic samples. Prior to the commencement of this test, the specific gravity bottle was weighed while empty (W_1) and when completely filled with water (W_4). Water inthe bottle was poured away and the bottle dried. A representative sample of approximately 50 g placed in the bottle was weighed (W_2). Water was poured into the bottle having the sample and the mixture stirred using the stirring rod. This bottle was then filled to the brim with water and left undisturbed for 24 hours before been weighed (W_3).

$$\text{Specific gravity of the sample} = (W_2 - W_1) / ((W_4 - W_1) - (W_3 - W_2))$$

4) Atterberg Limits : Liquid and plastic limits tests were carried out on the natural soil sample and stabilized soils.

a) Liquid Limit Test: A Casagrande liquid limit device was used. Prior to the commencement of the test, the sample was oven-dried, pulverized and sieved through the BS Sieve 36 (0.425mm). A representative sample was mixed with small amount of water at the start of the test and a part of the moist soil sample was placed in the brass cup using a knife-edge. The groove opening was made using the grooving tool. This test was carried out for groove closures at10,20, 30 and 40 blows. After each of the groove closures was obtained, moisture content samples were taken from the point of groove closure. The moisture cans containing the samples were weighed and kept in the oven and after 24 hours; the moisture cans were removed and reweighed. The moisture contents (%) for each of 10, 20, 30 and 40 blows were computed and the moisture content was plotted against the number of blows. The liquid limit of the sample is the moisture content (%) corresponding to 25 blows as obtained from the graphical plot.

b) Plastic Limit Test: The thoroughly mixed moist soil sample used for the liquid limit determination was spread on a glass plate and left for about 30 minutes. The moist sample was then rolled with the palm at a sufficient pressure to form a thread of uniform diameter using about 80 – 90 rolling strokes per minute. When the diameter of the rolled sample became about 3 mm, the thread was broken into several pieces, re-formed into a ball and re-rolled. The rolling and re-balling was continued until the thread crumbled under the pressure of rolling and the sample could no longer be rolled into a thread. The crumbled sample was taken for moisture content determination. Two moisture content samples were taken and their average (in percent) was computed as the plastic limit of the soil.

5) Compaction Characteristics: A representative portion of the lateritic soil sample was taken for modified Proctor compaction tests. Sufficient quantity (6 kg) of oven-dried soil sample was mixed in a large mixing pan. Using the weighing balance, the weight of the soil sample as well as the weight of the compaction mould with its base (without the collar) was determined. Water was measured, added in increments of 3% to the soil. Soil was placed in the mould and compacted in 5 equal layers, each layer was subjected to 56 blows of the 4.5 kg rammer. The drops was applied at a uniform rate not exceeding 1.5 seconds per drop, and a uniform coverage of the specimen surface by the rammer was ensured. The compacted soil while still in the mould and to the base was weighed and its mass recorded. Moisture content samples were taken from the top and bottom of the specimen. The moisture cans were filled with soil and the water content was determined, after 24 hours of being dried in the oven.

6) Strength Characteristics:

a) California Bearing Ratio (CBR): tests were conducted for the lateritic soil sample with 0%, 5 %, 8 % and 10 % steel slag addition respectively. Compacted soil sample were prepared in the CBR standard mould (used for compaction) and at the optimum moisture content, earlier determined from compaction test. The CBR was determined by conducting a load - penetration test on the unsoaked and soaked samples at each of the percent slag additions. For the soaked condition test, the base-plate and 4.5 kg of masses was placed on top of the compacted soil inside the mould, and the entire apparatus was immersed under the water in the soaking tank. The soaked index measuring tripod was attached on top of the immersed apparatus and the initial data was recorded. The soaked index was recorded after 24 hours. The apparatus was then removed from the soaking tank. The plate and collar of the mould was removed, but keeping the surcharge weight. The apparatus was placed under the penetration piston of the loading device. The loading device was initialized and the load at every 0.25 mm of deformation was recorded until 7.5 mm of deformation was achieved. Afterward, the mould was reversed and the load at various deformations was determined for the reversed side (bottom) of the specimen. The specimen was then removed from the loading device, and a small portion of sample was collected for the determination of the moisture content of the specimen after the CBR test.

b) Unconfined Compression Test: A cylindrical sample-forming device was used to produce a compacted cylindrical sample (of 50mm diameter and 100 mm height) at the optimum moisture content for each of 0 %, 5 %, 8 % and 10 % slag addition. The cylindrical soil sample was extruded and placed into the unconfined compression test device. The zero reading for both the load and the deformation was set and the loading device was initialized. Data was recorded at an interval of 0.2 mm deformation. After each of the samples reached its fracture point, the loading device was halted. Samples were then collected for moisture content determination.

7) Permeability: Air-dried soil sample was prepared, placed and compacted in the permeability mould in three layers. Each of the layers was subjected to 15 blows of the standard proctor rammer (2.5 kg). The base-plate was removed and the mould, containing the compacted soil, was clamped within the permeameter. The setup was totally immersed in water for 24 hours. Prior to the commencement of the test, the mass of the permeameter with the empty mould was obtained. The thickness of the compacted soil (height of mould) and the internal diameter (of the mould) were measured. The mass of the permeameter and the compacted soil was also measured. After 24 hours, the setup was removed from water and the standpipe was installed appropriately to the top of the permeameter. The initial height reading on the standpipe scale was obtained and recorded as H_1. With one person watching the standpipe and another person timing, the valve to the bottom of the permeameter was opened and the time for the water in the standpipe to drop through every 100 mm was measured. Thus, the reading after every 100 mm interval was recorded as H_2 and the time, t was also recorded. This test was performed for each of 0 %, 5 %, 8 % and 10 % slag additions.

VI. RESULTS AND DISCUSSION

TABLE IV: 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*

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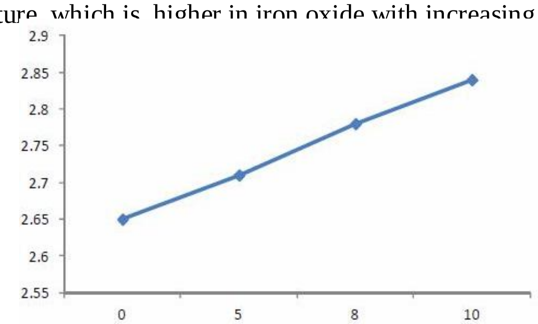
Unconfined Compressive Strength (kN/m^2)	*104*
Unsoaked CBR (%)	*5.1*
Soaked CBR (%)	*4.9*
Permeability (cm/s)	*1.68 x 10^{-4}*
Colour	*Brown*

In case of specific gravity the figure show 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 soil is within the range of 2.6 and 3.4, which was reported by Amadi (2010) for lateritic soils. Also, that of steel slag lies within the range of 3.2 and 3.6. Test result shows that at 5 %, 8 % and 10 % steel slag content the specific gravity is 2.71, 2.78 and 2.84 respectively. 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.

Specific Gravity



Slag content (%)

Fig 3: Variation of specific gravity with slag content

The particle size distribution of the lateritic soil sample is presented in Fig 4. It indicates that about half of the particles of soil sample are silt and clay-size minerals and about 5 % gravel and 45 % sand. The specified range of silt and clay contents in lateritic soils is from 12 % to 82 %. That of this soil sample lies nearly half way within this specified range..

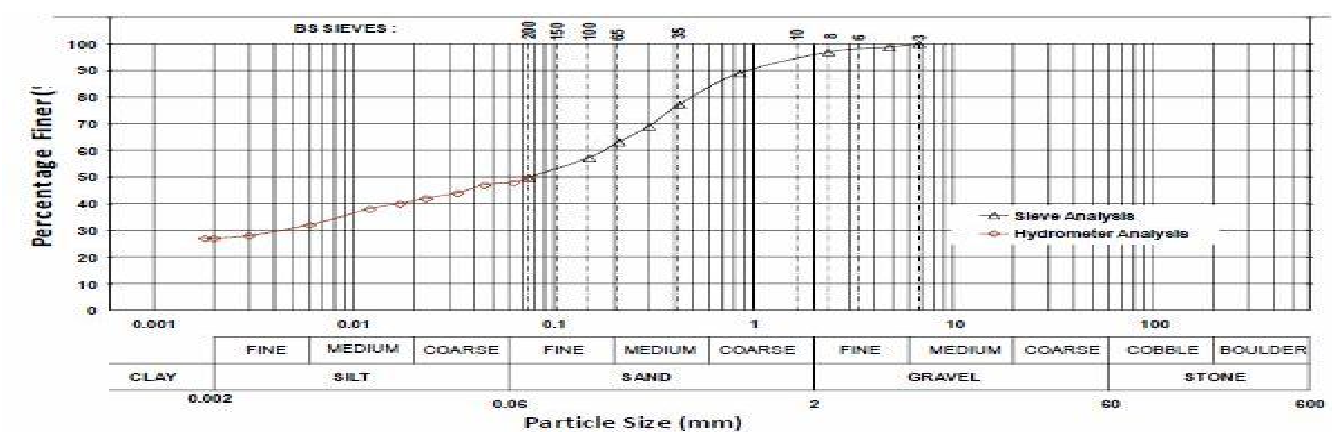


Fig 4: Particle size distribution of soil

The liquid limit tests were repeated twice and an average was taken and used. The laboratory result sheet for each of the Atterberg limits tests for 0 %, 5 %, 8 % and 10% slag contents are presented in the figure. With progressive enhancement 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 5, 6 and 7, 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.

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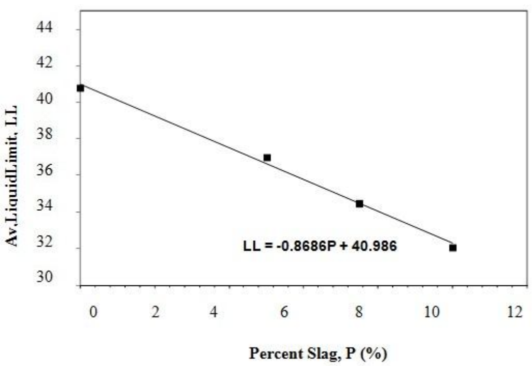

Fig 5: Variation of average liquid limit with slag content

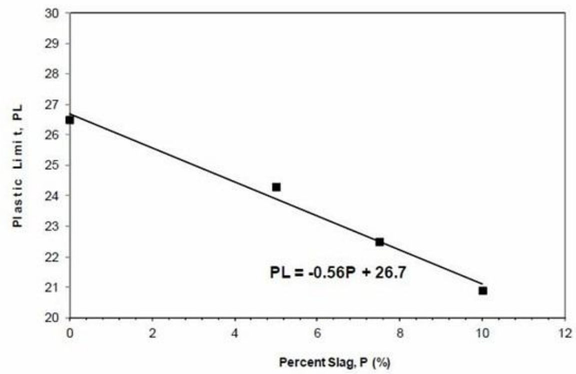

Fig 6: Variation of plastic limit with slag content

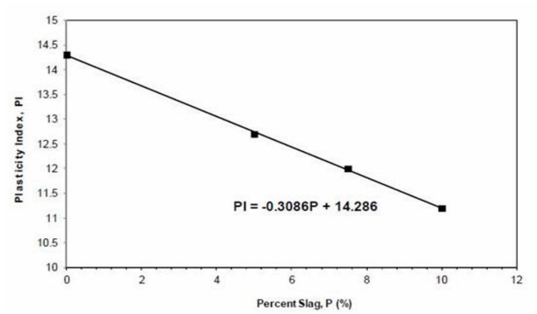

Fig 7: Variation of plasticity index with slag content

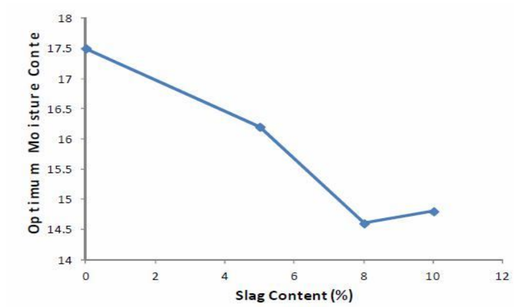

Fig 8: Variation of OMC with slag content

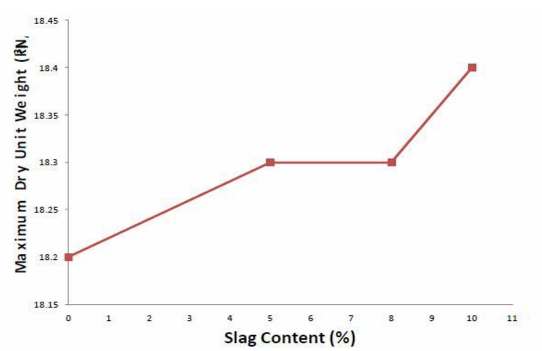

Fig 9: Variation of MDD with slag content

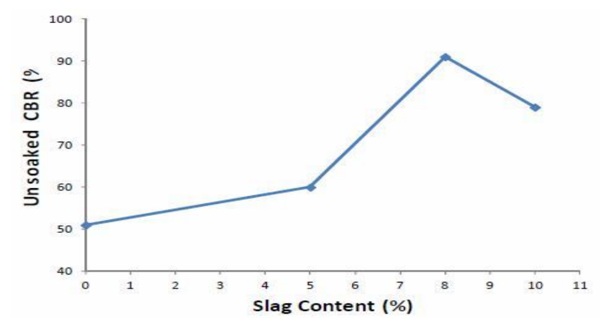

Fig 10: Variation of unsoaked CBR with slag content

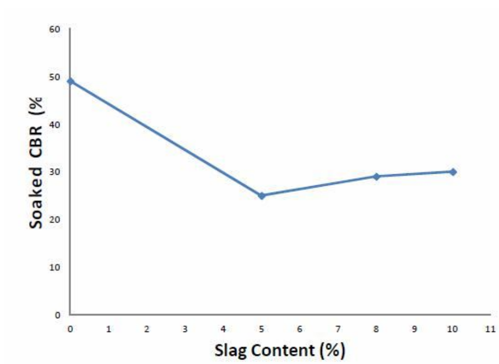

Fig 11: Variation of soaked CBR with slag content

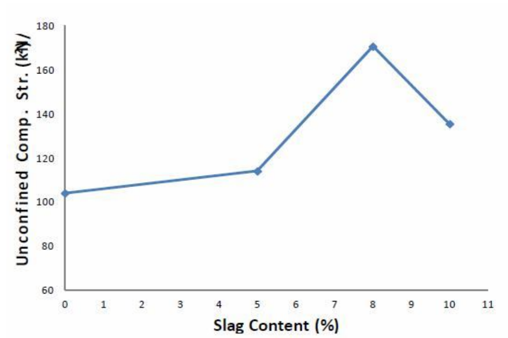

Fig 12: Variation of unconfined compressive strength with slag content

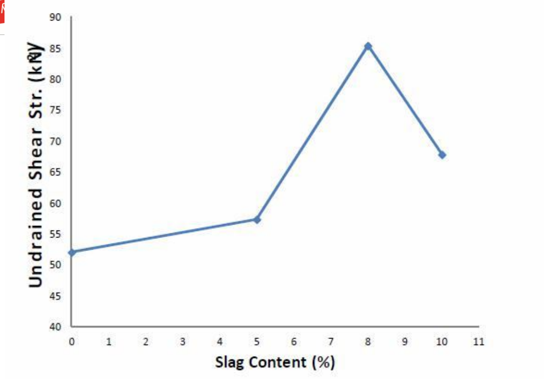

Fig 13: Variation of undrained shear strength with slag content

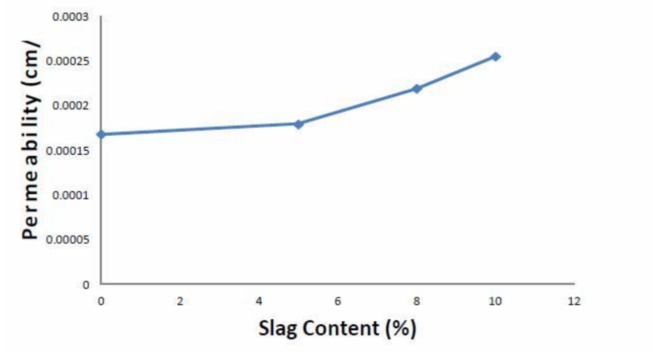

Fig 14: Variation of permeability with slag content

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 change in unsoaked CBR value with slag content can easily be seen in Figure 10. It indicates 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 with slag content can easily be seen in Figures 11. It indicates that the soaked CBR value for the soil-slag mixture initially decreased from 49 % for the 0 % steel slag content to 25 % for 5 % slag content before a progressive increase to 30 % for 10 % steel slag content.

Fig 12 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. The undrained shear strength responds in a similar way with increasing percent slag content (Fig 13). 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. Fig 14 shows that the permeability increased with increasing slag content from1.68 x 10^{-4}cm/s (for 0 % slag content) to 2.55 x 10^{-4}cm/s (for 10 % slag addition).

VII. CONCLUSIONS

Test results generally indicate 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 maximum dry unit weight of the soil increased with increasing steel slag contents 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. The permeability of the soil was generally increased with increasing steel slag contents.

Therefore, 8 % optimal stabilization of the A-7-6 soil with 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 (which satified the sub-base requirement) to meet requirement for use as only subgrade material. The results obtained show that steel slag can be more profitably used as an admixture with a conventional stabilizer such as cement or lime in order to meet the requirement for use as sub-base material.

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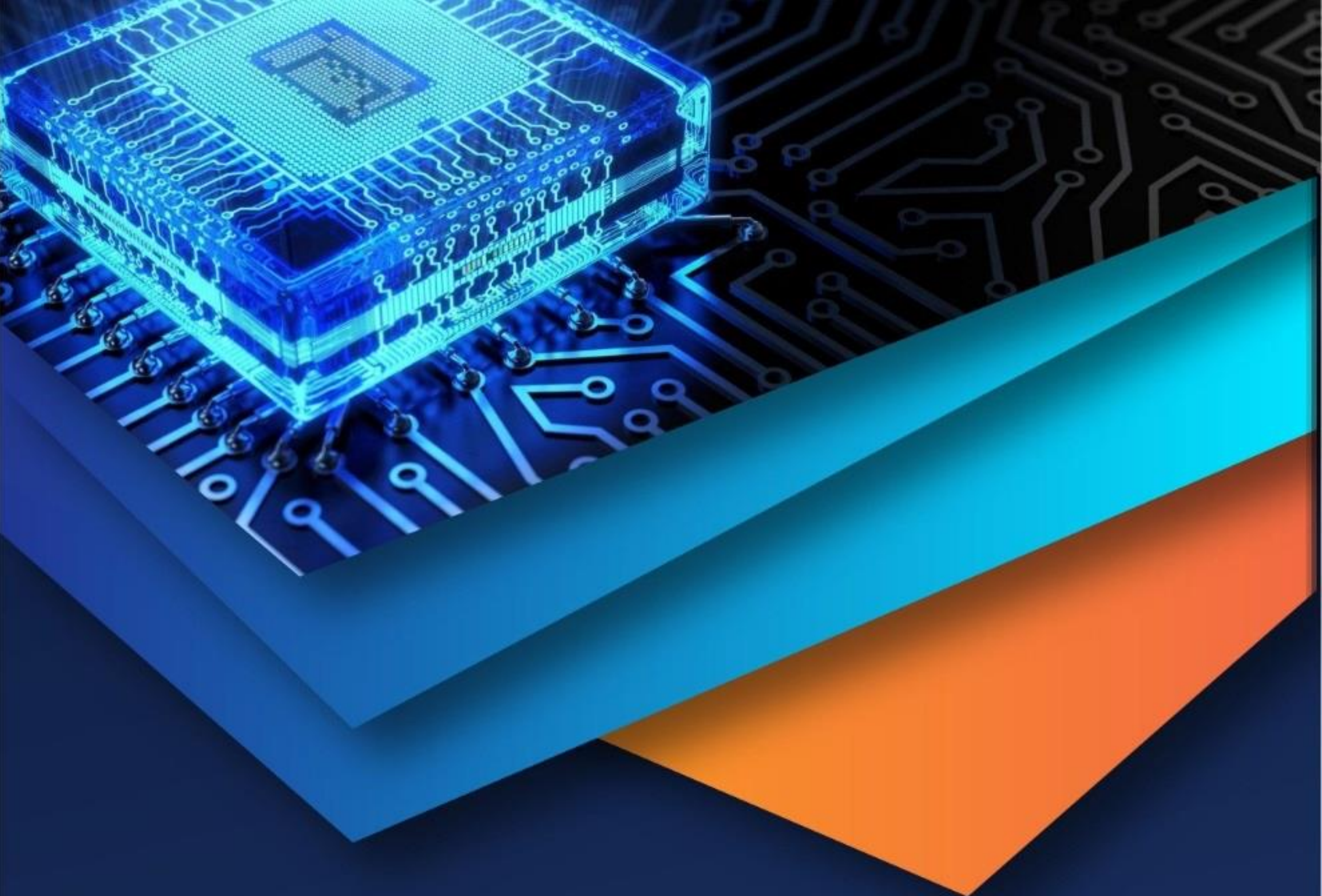

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