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Influence of Steel Slag Addition on Strength Characteristics of Clayey Soil

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Abstract: The disposal of industrial waste or by-products has become more difficult and expensive as a result of the increasing environmental regulations and shortages of suitable disposal sites. When molten steel is separated from impurities in steel making furnaces, steel slag is produced as a by-product of the process. In the construction industry, steel slag has long been used in various applications in the construction industry such as aggregates in road construction, railway ballast and hydraulic protection structures. Using steel slag for soil stabilization is a modern application of steel slag. In this study the main approach is to investigate the effect of steel slag on the strength characteristics of clayey soil. Steel slag is blended with clayey soil in amounts of 10%, 15%, 20%, 25%, and 30% of dry weight. In our study, the optimum content of steel slag was determined by considering the maximum unconfined compressive strength. A series of further laboratory tests have been performed on this optimum mix to evaluate its suitability as a stabilizer material. The test was also conducted with conventional stabilizing material such as l0% fly ash and 5%cement with clayey soil and the obtained optimum mix was determined. Then the results are compared accordingly. In the above study, it has been observed that the addition of steel slag results in significant improvement in strength parameter as compared to fly ash but less strength in case of cement. Also from the cost comparison, it has been observed that cost of optimum mix of steel slag is less as compared to cement. It is therefore used to stabilize clayey soil.

I. INTRODUCTION

A very large portion of our country, India has been covered with the expansive soil namely Black cotton soil which is very problematic deposits for the construction works. The major properties of these deposits are low shear strength, high plasticity, compressibility and high volumetric changes when saturated, so some geotechnical characteristics of it need to be addressed. As a result, they do not meet the requirements for use in civil engineering projects. At certain cases it is not available at the greater depth so geotechnical engineer design shallow or deep foundation.

Sometimes it's difficult to construct even deep foundation due to poor soil condition. In such cases to encounter the weakness of soil various methods of soil Stabilization and reinforcement techniques are adopted to stabilize and improve its geotechnical properties. There are various types of techniques employed for soil stabilization. Stabilization of soil can be accomplished with admixtures such as cement, lime, bitumen, chemicals, etc. or without adding admixture like compaction. It can also be done by adding certain reinforcement material or fibers to the soil.

The stabilization of soil is performed when it is easy to overcome a deficiency in a readily available material rather than bring in one that fully complies with the requirements of the specification. Recently some industrial by-product is added with the soft soil to increase engineering properties, which help in transforming the wastes of industry to valuable materials or into the most desirable utilizations. One of the commonly available products of industry i.e., steel slag (major waste product of steel industry) is being used in construction industry for the aggregated in road construction, railway ballast and hydraulic protection structures. Whereas free lime present in the steel slag, create expansion & therefore it has limited application. Since the steel slag having the presence of free lime & other similar chemical composition & mineralogy for Portland cement. Which makes it more potential for further usage of steel slag in the construction industry in the aspect of soil stabilization.

As defined by the Federal Highway Administration (FHWA), steel slag is a by-product of steel making produced in furnaces during the removal of impurities from molten steel. For production of steel, Iron is Oxidize by adding the limestone & coke for removing excess product like silicon & carbon. Since the steel slag contains high amount of iron & it has similar physical characteristic to air-cooled iron slag. In India, approximately 24 lacs tons of steel slag are produced each year by different steel industries, and globally, approximately 96 to 145 million tons of steel slag are produced annually.

This study focuses on conducting the experimental analysis on the addition of steel slag to the clayey soil and studying the effect on compaction characteristics, unconfined compressive strength, shear strength parameters, swelling pressure and CBR value. Further effect of different stabilizers has also been studied on the optimized soil slag mix.

II. LITERATURE REVIEW

Akinwumi et.al. (2013) investigated the effect of adding pulverized steel slag on some geotechnical properties of lateritic soil. Lateritic soils exhibit poor engineering properties such as high plasticity, poor workability, low strength, high permeability, tendency to retain moisture and high natural moisture content (Maigien, 1964). Steel slag samples, which had been exposed to weather for about 8 months and air-dried in the laboratory for about 4 months has been used in the presented study. The sizes of samples, collected for steel slag had ranging from 250 – 300 mm & they were crushed down to size of less than 0.425 mm. X-Ray Fluorescence test showed that the percentage composition of CaO was determined to be 7.73% by weight. Steel slag was added to the soil sample in 5, 8 and 10% by weight of the sample. Atterberg's limits, compaction, California bearing ratio (CBR), unconfined compression and permeability tests were performed on each of them.

With increasing the percentage of steel slag content, it was found that the specific gravity of the mixture increases and the liquid limit, plastic limit and plasticity index progressively decreased. The dry unit weight of soil slightly increased due to presence of higher slag content in steel. The 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.

Further they studied the effect on UCS and reported that the initial increase in the unsoaked CBR and UCS values of the soil from 0% slag content to 8% slag content could probably be due to cation exchange at the surface of clay particles as the Ca2+ in the stabilizer reacted with the lower valence metallic ions in the clay microstructure, which resulted in agglomeration and flocculation of the clay particles and subsequent reduction in the unsoaked UCS values suggests that the limit of influence of the solidification effect had been reached.

It was concluded that the plasticity of the optimum mix decreases to 66.2%. While the strength of the optimum mix increases to 96% compared to the virgin soil. The CBR of the optimum mix increases to 97.5% compared to the subgrade clay soil. Based on strength, CBR, and plasticity value, the stabilized soil is as durable as the subgrade material. The dynamic properties of stabilized subgrade layer show increase in the soil stiffness about 58-78%. The soil-SSL- RHA mix gives better savings cost than conventional stabilization systems.

Yildirim and Prezzi (2015a) studied to determine the engineering properties (compaction characteristics, shear strength behavior, mineralogy, and long-term swelling potential) of BOF steel slag which is used as a fill material in geotechnical applications. From the results of grain size distribution curve it has been found out that BOF steel slag cools in the pits, it breaks down into a wide range of particle sizes & thus slight varies in gradation is expected.

A. *Critical Appraisal*

A comprehensive review of the literature regarding the steel slag as a stabilizer can be summarized by the following points:

1) Steel slags has been used as coarse and fine aggregate in asphalt mixes, as concrete aggregate, as cement additive, and as raw material for cement clinker.
2) Steel slag has properties like Portland cement, and sometimes it is a weak Portland cement due to its low content of tricalcium silicate.
3) Steel slags have favorable strength characteristics when compared with most natural soils and can be used as a geomaterial in various applications.
4) Limited studies have been reported for steel slag as stabilizing agent for the clayey soil due to some of the mineral phases found in the steel slag.
5) Several researchers have attempted to study the effect of steel slag as a stabilizer in soil stabilization.

B. *Scope of the Study*

A study is conducted to determine the impact of steel slag addition on strength characteristics of clayey soils. The purpose of this research was to use steel slag for stabilizing clayey soil. The specific objectives of this study include:

1) Determining the engineering properties of clayey soil.
2) A study of the physical characteristics and chemical composition of steel slag.
3) Determination of the optimum steel-slag content required.
4) Evaluation of the index properties and strength properties of clayey soil/steel slag mixtures.
5) To study the effect of fly ash and cement as a stabilizing material on clayey soil and results are compared accordingly.

III. TESTING METHODOLOGY AND EXPERIMENTAL INVESTIGATION

A. Experimental Program

1) *Phase 1:* Material Classification and Identification.
2) *Phase 2:* Determination of Optimum Mix.
3) *Phase 3:* Test on Optimum Soil-Slag Content.
4) *Phase 4:* Effect of Stabilizers on Soil-Slag Content.
5) *Phase 5:* Cost Estimation

B. Sample Preparation

Following steps are carried out while adding steel slag to the soil sample:

1) The soil samples were first dried in an oven at 105 degrees Fahrenheit and sieved through 4.75 mm meshes.
2) The required number of raw materials (i.e. Several samples of dry soil, steel slag, and water) were calculated and weighed.
3) The soil and steel slag were mixed by hand mixing process and after that required amount of water is added and hand mixing is done for several minutes so as to obtain homogeneity of the specimen.
4) In accordance with the standard proctor compaction test, all soil samples are compacted at their respective maximum dry density (MDD) and optimum moisture content (OMC).Then further testing was carried out.

C. Testing Program

Firstly, soil sample were tested for number of properties of the soil and accordingly the soil has been classified. A variety of steel slag proportions have been tested in order to determine the optimal mix. As the optimum mix has been found out, the series of tests were carried out to compare the amount of improvement brought by mixing the steel slag to the soil at optimum mix. Table shows the testing program carried out for soil and optimum mix.

Tests	No. of Samples		Reference Code
	Soil	Optimum Mix	
Liquid limit	1	1	IS: 2720 (Part-5) & IS : 2720 (Part-6)
plastic limit	1	1	
Shrinkage limit	1	1	
Grain Size Classification	1	1	IS : 2720 (Part -4)
Free swell	1	1	IS : 2720 (Part -40)
Standard Proctor Test	1	1	IS : 2720 (Part -7)
Unconfined Compressive Test	1	1	IS : 2720 (Part -10)

D. Mix Proportion

1) *For optimizing Steel Slag Content:* For optimizing the steel slag content to find out optimum mix ratio the percentage of the steel slag content has been varied at different ratio by weight given in Table. Tests have been performed on every mix proportion by a standard proctor and an unconfined compression test. Based on the maximum unconfined compressive strength, the optimum mix is chosen.

Designation	% Soil	% Steel Slag
100%S	100	0
90%S+10%SS	90	10
85%S+15%SS	85	15
80%S+20%SS	80	20
75%S+25%SS	75	25
70%S+30%SS	70	30

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2) *Effect of Stabilizers on Clayey Soil:* To study the effect of different stabilizer on clayey soil two stabilizer namely cement and fly ash has been used with following Mix Proportion.
1) Clayey Soil + 5% Cement
2) Clayey Soil + 10% Fly Ash

E. Testing Procedure

1) *Standard Compaction Test:* In order to conduct a standard Proctor, the following procedure was followed as given in IS: 2720 Part 7. The soil is compacted using the standard proctor hammer weighing 2.5 kg in 3 layers. Each layer is subjected to 25 blows. The compaction curves for soil are obtained. Following Figure shows the Standard Proctor Apparatus used at the time of test.

2) *Unconfined Compression Test (UCS):* Unconfined compressive strength experiment is performed to determine unconfined compressive strength of the soil sample, which is used for calculating the unconsolidated and undrained shear strength of unconfined soil. UC strength (qu) is defined as the stress above which an unconfined cylindrical soil sample can't withstand simple compression. The experimental setup constitutes of the compression device and dial gauges for load and deformation shown in the figure below. We calculated the cross-sectional corrected area by dividing the area by (1-e) and then calculated the compressive stress in each step by dividing the load on the corrected area. Samples were also being tested after respective curing period. Curing of the samples were carried out as, samples were casted as per the UCS sample sizes then they have kept in the airtight plastic bag, then the plastic bag has been immersed in the water it done to prevent the moisture loss from the samples. Samples were tested for UCS values after the respective curing periods.

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IV. RESULTS AND DISCUSSION

A. Material

1) *Soil Sample:* Table given below shows the soil characteristics which were evaluated to classify the soil with their respective IS Code. The soil is classified as silt with high compressibility having the specific gravity of 2.65 and free swell index of 71%. Figure shows the grain size distribution for the clayey soil.

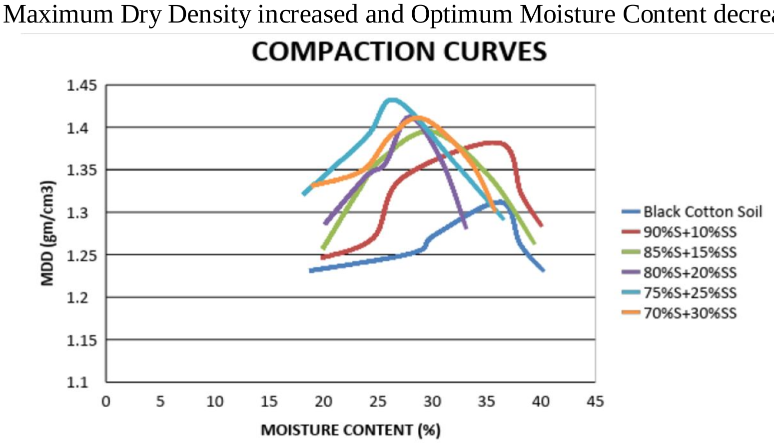
Tests	Characteristics	Values	IS Code
Particle Size Distribution	Gravel (%)	1	IS 2720 (Part-4)
	Sand (%)	8	
	Silt and sand (%)	91	
	Classification of Soil	MH	IS : 1498
Physical Properties	Specific Gravity	2.65	IS: 2720 (Part 5)
	Liquid Limit (%)	68	
	Plastic Limit (%)	38	
	Plasticity Index	29	
	Shrinkage Limit (%)	14	IS:2720 (Part 6)
Engineering Properties	Optimum Moisture content (%)	32.5	IS:2720 (Part 6)
	Maximum Dry Density (KN/m3)	13.24	IS:2720 (Part 7)
	Unconfined Compressive Strength (KN/m3)	352.6	IS:2720 (Part 10)
	Free Swell	71	IS:2720 (Part 40)

2) *Steel Slag:* The following table summarizes the physical properties of steel slag. It has been reported that steel slag has a specific gravity of 3.19. The higher value of steel slag is due to iron oxide present in one of its phase compositions.

Characteristics	Values
Specific Gravity	3.19
Colour	Greyish
Natural Moisture Content	0.26%
Cu	2.09
Cc	1.65

B. Results for Soil – Slag Mix

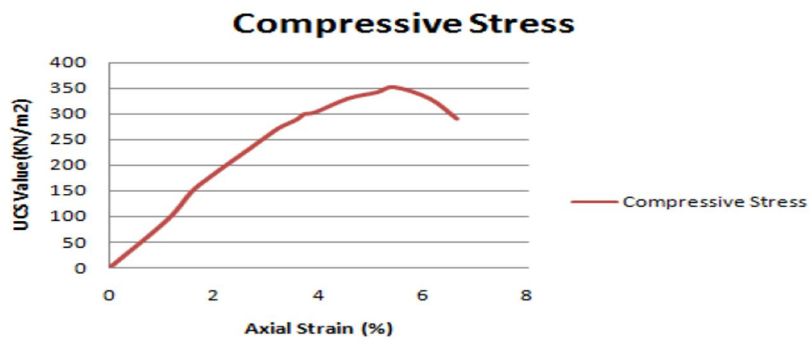
1) *Standard Proctor Test:* A standard proctor test has been conducted on clay soil with varying percentages of steel slag content. Graph given below shows compaction curves for different combination of steel slag. From the graph, we can see that as the steel slag content increased Maximum Dry Density increased and Optimum Moisture Content decreased.



This graph depicts the variation in optimum moisture content based on slag content and it is observed that as the percentage of steel slag increases OMC decreases up to 25%. The decrease in the OMC could be possible due to hydrophobic nature of the steel slag and as the addition of slag content in the soil–slag mix always got accompanied by the reduction of fineness content in the mix, and consequently, water-holding capacity of the mix got diminished and therefore such results were observed. Also, the variation of maximum dry density with steel slag content has been seen that as the percentage of steel slag increases MDD also increases. MDD increases because steel slag has a higher specific gravity than clayey soil.

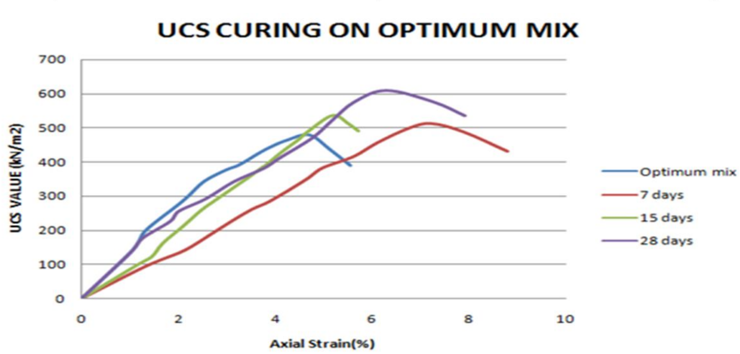
2) Unconfined Compression Strength

The UCS test on Soil is first performed and compressive strength of soil is found. Graph given below shows the UCS value of the soil.



The unconfined compressive strength test has been performed on clay with different steel slag content according to IS 2720-10 (1991) on a sample size of 38mm×76mm. Test performed on the Standard Procter apparatus for different percent of steel slag and soil shows the optimum mix of steel slag and soil which has been taken for carrying out further tests of UCS for different curing periods. The optimum mix so obtained is 75%S+25%SS having MDD and OMC. The increase in the value is due to the frictional resistance offered by the steel slag due to a presence of wide range of particles of steel slag. The addition of slag beyond 25% leads to the reduction in strength value this may be because that limit of solidification as reached and addition beyond that will not contribute to increased strength. Further, the optimum mix has been cured as per curing method mentioned in the experimental methodology section for a period of 7, 15 and 28 days and test has been performed. Graph shows the UCS curve for different curing period.

Curing Days	UCS Value (kN/m^2)
0	478.20
7	512.36
15	536.90
28	610.20



From Graph, it has been clearly observed that there is a gain in the strength values for the samples treated with optimum mix proportion. This increase in value can be explained by the fact that steel slags contain certain minerals that contribute to the pozzolanic reaction that contributes to the formation of a compound which leads to strength of the mix.

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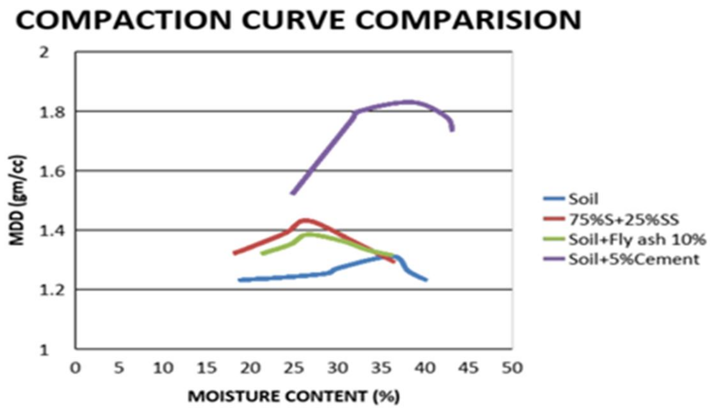
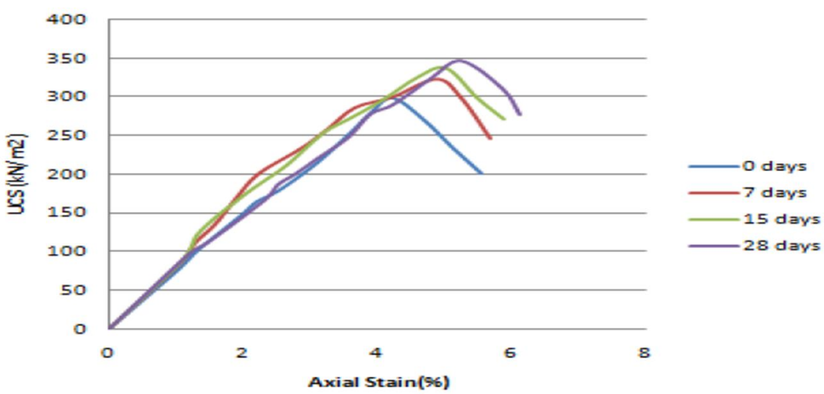
C. Results of Soil with Different Stabilizers

From the laboratory investigation it was found that with the addition of steel slag at an optimum mix ratio improved the strength properties of the soil. Based on the test performed the percentage of cement and fly ash was taken has 5% and 10% and their effect on soil is evaluated and compared.

1) *Standard Proctor Test:* Standard Proctor test has been performed by adding fly ash and cement separately to soil and optimum mix is determined and the results were evaluated. From figure given below, it has been observed that the addition of 10% fly ash to the soil leads to the increase in the MDD and the corresponding decrease in OMC values and in the case of cement MDD is more than the steel slag and fly ash.



The Graph given below shows the results of UCS test on optimum mix of fly ash with different curing period. It is observed that there is increase in strength as no of curing days' increases and at the end of 28 days the UCS value is 347.78kN/m^2, it is less than the optimum mix of steel slag.



The below graph shows the UCS value of optimum mix of cement with different curing period. It has been observed that as the number of curing days increases the UCS value is also increases and at the end of 28 days the UCS value is 1995.56kN/m^2. The UCS value is more as compared to optimum mix of steel slag.

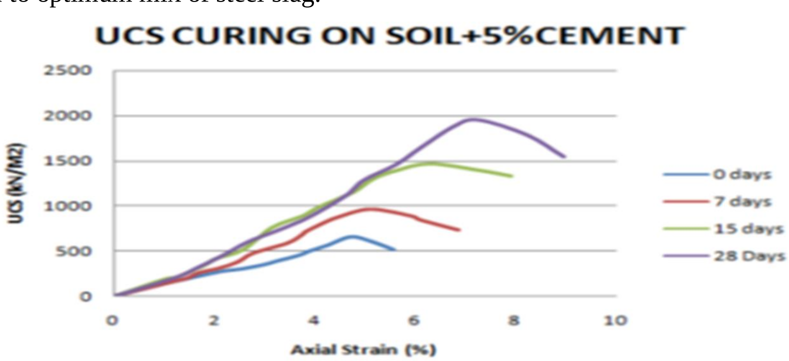


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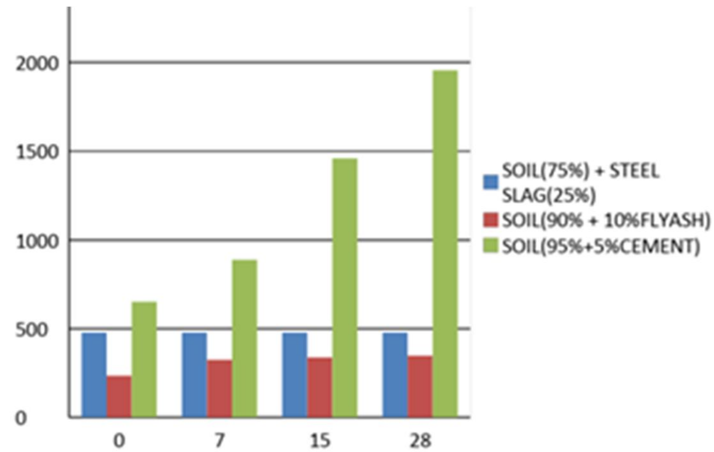
Figure given below shows the comparison of UCS Test on a different stabilizer. It has been seen that the UCS value is increases as the number of curing days' increases. But the UCS value is more in case of optimum mix of cement as compared to optimum mix of steel slag and fly ash.



D. *Cost Comparison on Different Stabilizers*

The cost comparison has been carried out for 1km road having 3.75m width and 150mm thickness of subgrade. The Volume required for the subgrade is calculated with different stabilizer. After that the rates per metric ton taken from the SSR then the total cost required per 1km road was calculated. Table given below shows that the cost of soil with cement is more compared to steel slag and fly ash. Also, the cost of 1Km road with optimum mix steel slag can be reduced by adding fly ash.

Sr.No.	Stabilizer	Quantity(MT)	Rate per MT	Total Cost
1	Steel Slag	316.31	600	1,89,786
2	Fly Ash	126.52	600	75,912
3	Cement	63.26	4200	2,65,692

V. CONCLUSIONS

Based on the experimental analysis in this study, the following conclusions have been drawn.

1) Clay soil was mixed with various proportions of steel slag and based on the OMC and MDD value the optimum mix has been found out as 75% S + 25% SS.
2) UCS value at optimum mix is increased to 33.92%.
3) UCS value for different curing period shows increase in the strength with increase in curing period.

The result of the presented study reflects that the steel slag can be used as a stabilizer for the clayey soil as addition of slag improves the geotechnical properties of the mix. But steel slag alone cannot counteract the expansive nature to much extent. But with the addition of some of the other activators such as lime can help us to alleviate the problem to acceptable limits.

Cost of cement mix is more as compared to steel slag mix and cost of fly ash mix is less, therefore fly ash can be added to steel slag mix to reduce the cost.

A. *Future Scope of the Work*

1) More investigation is required to further understand the behavior of steel slag.
2) Different combination can be worked out to test its suitability for various geotechnical applications.
3) Steel slag can also be tested with various other activators to evaluate its performance with other materials.
4) The total cost of subgrade with steel slag can be reduced by adding fly ash in the soil as cost of fly ash mix is less as compared to steel slag mix and cement mix.

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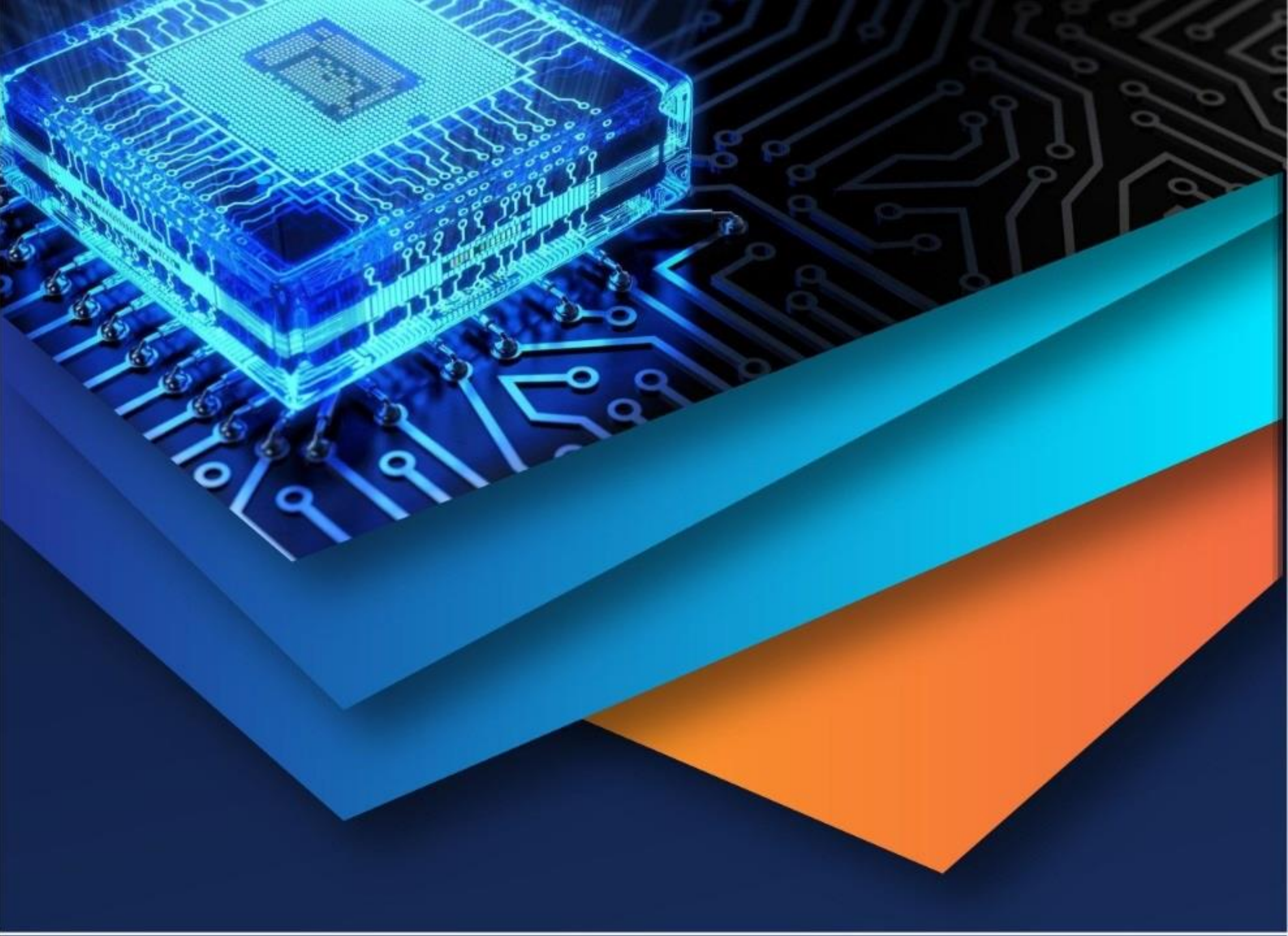

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