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An Experimental Study on Efficiency of Copper Slag and Zycobond in Improving Properties of Expansive Soil

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Abstract: ***Expansive soils, which are considered as problematic soils, swell when they imbibe water and shrink when water evaporates from them. Because of the alternate swelling & shrinkage the structures founded in these soils get severely cracked resulting in a huge financial loss. Present study was undertaken to evaluate the strength properties of soil after addition of stabilizing agents like industrial by-products such as Copper Slag and a chemical stabilizer named Zycobond. Laboratory tests were conducted to analyze the influence of varying percentages of Copper Slag (6%, 10%, 14%, 18%and 22% by dry weight of soil) along with a fixed dosage of Zycobond. Differential free swell Test, Modified Proctor Test, Atterberg's Limits, California Bearing Ratio (CBR) and Triaxial tests were performed. The obtained results indicated that the addition of Copper Slag and Zycobond significantly reduced the Liquid limit , plasticity index and increased the maximum dry density. The CBR values also showed remarkable improvement. In this study the 82% ES + 18% CS mix was found to be optimum and with the addition of chemical additive Zycobond in 1.5 % to this mix , the soil attains greater CBR value.***
Keywords: Expansive Soil(ES), Copper Slag(CS), Zycobond(ZB), Soil Stabilization, CBR.

I. INTRODUCTION

Expansive soil is a clayey soil that undergoes significant volume change due to variation in its moisture content. This volume change happens due to the presence of clay minerals, mainly Montmorillonite, Smectite and Bentonite. Swelling of clay soil is a very troublesome subject in various fields of civil engineering. It is characterized as high water content, high compressibility, and very low bearing capacity, making it unsuitable for direct use in foundations or pavement construction. Heaving by swelling soils can also cause slope failures, roads to buckle, driveways to shift, and structural walls can collapse. Stabilizers like lime, cement, or other binders can used to improve the soil properties.

A. Copper Slag

Copper Slag is a by-product of copper smelting and refining process. It is a low free silica by product that meets all the environmental standards. It also has a high strength-to-water ratio, making it an effective option as fill material. Its reuse in geotechnical engineering contributes to waste minimization, cost reduction, and improved soil properties such as shear strength and permeability.

B. Zycobond

Zycobond is an additive for soil stabilization. It is composed of an acrylic co-polymer, soluble in water, stable to heat and ultraviolet radiation. Its main action, therefore, is to conglomerate the soils.Reacts with the particles present in the soil, transforming its surface and giving them properties that increase its size and hardness, improving the mechanical properties of the treated soil and thus reducing the generation of dust in the soil. suspension.

II. OBJECTIVE OF THIS PRESENT STUDY

1) To determine the properties of Expansive Soil.
2) To access the influence of varying dosage of Copper Slag (6%, 10%, 14% ,18% and 22% by dry weight of soil) on strength characteristics.
3) To find out the optimum dosage of Copper Slag to achieve maximum strength.

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4) To access the effect of varying dosage of Zycobond (0.5%, 1%, 1.5% and 2% by dry weight of soil) on the strength properties.
5) To find out the optimum dosage of Zycobond with addition of Copper Slag to achieve maximum strength of soil.
6) To study the performance of soil after adding mechanical and chemical stabilizers.

III. LITERATURE REVIEW

Barvan et al. (2005) Studied the expansive soil properties using 0, 10, 20, 30, 40, 50, 60, 70. and 80% of the dry weight of copper slag, The MDD increased and decrease in OMC with the increments of copper slag material and the Free swell index decreased by 60% with respective to soil + 70% CS. However, the soaked CBR value improved only after adding 2% of cement and the expansive soil found to be suitable as a subgrade by utilizing 50% CS waste along with 2% cement.

P.Goud et.al, (2018) studied about the different combinations of copper slag and rice husk ash. The best combination was discovered to be 64 % BC+30% CS+6% RHA. The free swell of soil treated with RHA and CS decreased dramatically from 100% to 20.4%. The MDD of the treated soil changed slightly, the strength of the ideal blend was 12.7 % according to the unsoaked CBR test. The stabilized soil mixtures demonstrated acceptable strength qualities and can be used for the low-cost building of dwellings and road infrastructure.

Prof. Mohammed A. Qureshi (2015) conducted a study on Improvement in Soil properties of Expansive Soil by using Copper Slag it has been found that The CBR value of this proportion is increased up to 4.12 as compare to black cotton soil and satisfied the criteria for use in road pavement. CBR value of combination of 60% B.C. soil with 40% C.S. is increases and further it tends to decrease.

Karthik, Rakshith Reddy, Sandeep Kumar, Manoj Kumar R. Studied Stabilization of black cotton soil using copper slag for pavement construction. According to the test results, The plasticity of the optimum mix with copper slag decreases. High value of MDD in combination of mix with copper slag and further it tends to decrease. The shear strength of optimum mix with copper slag was higher than the shear strength of the clay soil. The free swell index reduced by the addition of Copper slag.

Sharan Kumar B M, Dr. Vageesh Mathada, Vishwanath D (2018) "The use of copper slag and polypropylene fiber to strengthen the engineering properties of black cotton soil''. It is observed that The unsoaked California bearing ratio value of copper slag (6% to 24%) when treated with BC soil, CBR values ranges from 4.89% to 3.22%. The unsoaked California bearing ratio value when polypropylene fiber (0.5% to 2%) mixed with BC soil, CBR value ranges from 5.80% to 3.22%.

M. Prabodh Kumar, R. Dayakar Babu and K. Ramu "Use of Zycobond in Enhancing the strength of Expansive soil modified with Rice Husk Ash''. The results obtained are Liquid limit value decreased by 24.35 % and Plastic limit value increased by 27.01 % and Plasticity index value decreased by 62.87% on treating with RHA and Zycobond.

B. Veera Siva Prasad "Use of nanomaterials like Terrasil, Zycobond as admixtures to improve the strength characteristics of expansive soil' 'It is observed that Addition of 1.5% of Terrasil and 1.5 % of Zycobond increases the MDD from 1.64 g/cc to 1.74 %.

Shilpa Devi Gadde, Mohammed Ibrahim "An experimental analysis on the influence of copper slag as stabilizer on black cotton soil'', obtained results are The addition of copper slag increases the CBR test consistently from 5.04% to 5.4%. The maximum CBR test value is obtained at 15 %. The addition of copper slag increases the dry density value from 1.1 to1.215 g/cc. The maximum dry density value is obtained at 15%.

IV. METHODOLOGY

The experimental program was carried out in several stages to evaluate the performance of marine clay stabilized with Copper Slag and Zycobond. The overall procedure included soil collection, material preparation, proportioning of mixes, laboratory testing, and analysis of results. Various test like differential free swell, specific gravity , Atterberg's limits, Modified proctor test, CBR were conducted to examine the performance of soil after being stabilized.

A. Soil Collection

Expansive Soil required for the study was collected from allavaram, Amalapuram, East Godavari district, Andhra Pradesh. at a depth of about 1.5 m below ground level to avoid surface contamination. The soil samples were carefully excavated, transported to the laboratory, and air-dried under shade to preserve their natural properties. Lumps were broken down manually, and the material was sieved through a 4.75 mm IS sieve to obtain a uniform soil sample for testing.

B. Materials

1) Expansive Soil: The collected soil was used as the base material for stabilization. Its index and engineering properties were determined through Preliminary testing.
2) Copper Slag: IT was procured from a metal casting industry in Faridabad. Since it is glassy material with particle size 1mm it is used directly.
3) Zycobond: Zycobond, a liquid chemical stabilizer, was used in diluted form as per the manufacturer's recommendation. Its role was to enhance the inter-particle bonding and improve the overall strength of the soil mixes.

C. Mix Proportions

The stabilization process involved preparing soil samples with different proportions of Copper Slag and Zycobond. Five mix ratios were considered, with 6%, 10%, 14%,18% and 22% for Copper Slag and 0.5%, 1%, 1.5%, and 2% for Zycobond (by dry weight of soil) added to Expansive soil. For each percentage, two sets of samples were prepared: one with only copper slag and another with Copper Slag combined with Zycobond. This allowed a comparison between mechanical stabilization and combined mechanical–chemical stabilization.

Table -1: Mix Proportions for testing Soil

S.NO	Stabilizing Agent	Mix proportions
1	Copper Slag	6,10,14,18,22
2	Zycobond	0.5,1,1.5,2

D. Laboratory Testing

To assess the influence of Copper Slag and Zycobond on the properties of Expansive soil, a series of laboratory tests were carried out in accordance with relevant IS codes. The tests conducted are as follows:

1) Differential Free Swell (DFS) Test (IS 2720 – Part 40): The free swell behavior of the untreated and treated Expansive Soil was studied to evaluate the reduction in expansiveness after stabilization. It measures how much the soil expands when immersed in water compared to when it is immersed in a non-polar liquid (usually kerosene), which does not cause swelling.
2) Atterberg Limits Test (IS 2720 – Part 5): This test was performed to determine the liquid limit, plastic limit, and plasticity index of both untreated and stabilized soil samples. It tell us how a fine-grained soil will behave with changing moisture.
3) Modified Proctor Compaction Test (IS 2720 – Part 7): Compaction tests were conducted to establish the maximum dry density (MDD) and optimum moisture content (OMC) for each mix proportion. The optimum percentage of Copper Slag and Zycobond for improving soil densification was determined.
4) California Bearing Ratio (CBR) Test (IS 2720 – Part 16): Both soaked and unsoaked CBR tests were conducted to determine the load-bearing capacity of the stabilized soil. The results provided a measure of the potential application of the stabilized Expansive soil as foundation material.
5) Triaxial Compression Test (IS: 2720 Part 11 – 1993): The triaxial compression test is conducted to determine the shear strength parameters of soil, namely cohesion (c) and angle of internal friction (ϕ), under different drainage and loading conditions. It provides a realistic simulation of field stress conditions by applying both confining and axial pressures on the specimen. The test helps in understanding the behavior of soil under controlled stress paths and is useful for analyzing the stability of slopes, foundations, and embankments.

Table -2: Properties of Expansive Soil

S.NO	NAME OF THE EXPERIMENT	VALUE
1	Particle size distribution	
	Sand (%)	9.6
	Silt (%)	14.4
	Clay (%)	69
2	Atterberg's Limit	
	Liquid Limit (%)	67
	Plastic Limit (%)	28.3
	Plastic Index (%)	38.6

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3	Modified Compaction Results	
	Optimum Moisture Content (%)	28.06
	Maximum Dry Density (g/cc)	1.51
4	Differential Free Swell (%)	95
5	Specific gravity	2.51
6	IS Classification	CH
7	CBR(%)	1.34
8	Cohesion (KN/m^2)	95.41
9	Angle of Internal friction (º)	2.4

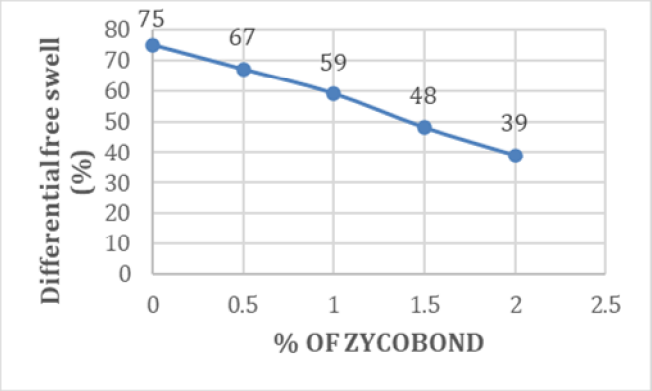
V. RESULTS AND DISCUSSION

A. *Differential free swell*

Table -3: Results of Free swell index test

S.NO	MIX PROPORTION	DFS
1	82% ES with 18% CS + 0 %ZB	75
2	82% ES with 18% CS + 0.5%ZB	67
3	82% ES with 18% CS + 1%ZB	59
4	82% ES with 18% CS + 1.5% ZB	48
5	82% ES with 18% CS + 2%ZB	39

Fig -1: Variation in DFS of Expansive soil and Copper Slag treated with percentage of Zycobond



B. *Atterberg's Limit Test*

Table -4: Results of Atterberg's limit test

S.NO	MIX PROPORTION	LL (%)	PL (%)	Ip (%)
1	82% ES with 18% CS + 0 %ZB	59.0	35.8	23.2
2	82% ES with 18% CS + 0.5%ZB	57.3	36.7	20.5
3	82% ES with 18% CS + 1%ZB	54.4	38.4	16

4	82% ES with 18% CS + 1.5% ZB	51.8	39.1	12.7
5	82% ES with 18% CS + 2%ZB	49.6	40.1	9.5

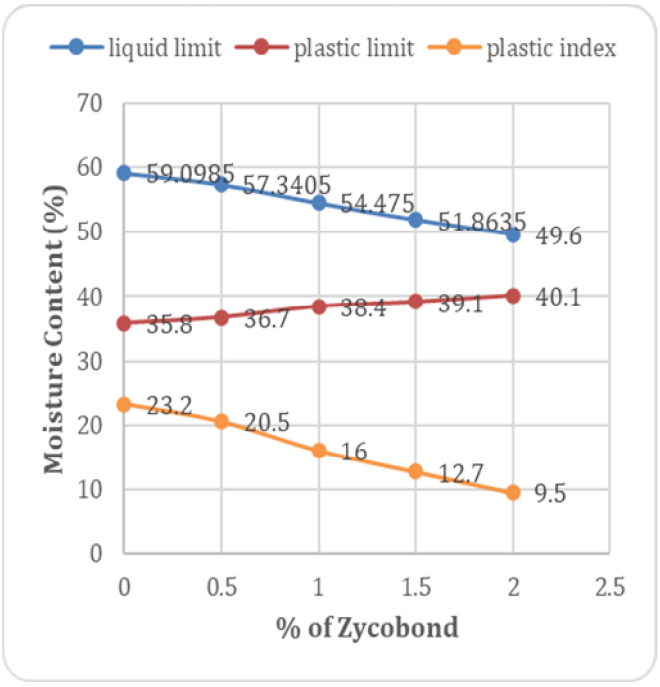


Fig -2: Variation in LL, PL & PI of Expansive Soil and Copper Slag treated with percentage of Zycobond

C. Modified Proctor Compaction Test

Table -5: Results of Modified Proctor Compaction Test

S.NO	MATERIAL PROPORTION	OMC	MDD
1	82% ES with18 % CS + 0% ZB	17.63	1.74
2	82% ES with18 % CS + 0.5% ZB	17	1.77
3	82% ES with 18% CS + 1% ZB	16.06	1.82
4	82% ES with 18% CS + 1.5% ZB	15.18	1.87
5	82% ES with 18% CS + 2% ZB	14.76	1.81

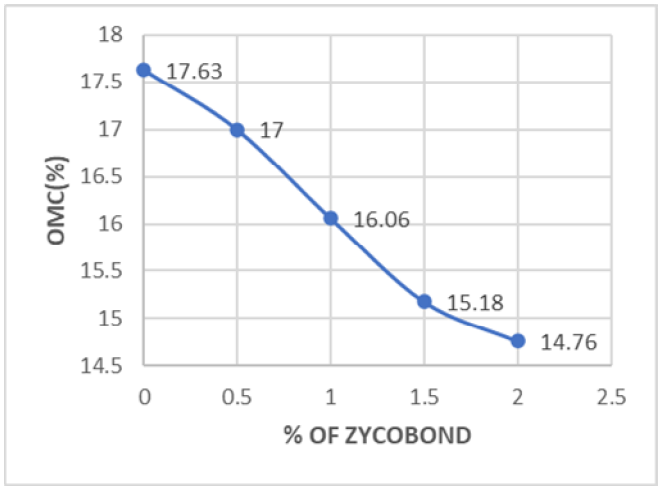


Fig -3: Variation in OMC of Expansive Soil and Copper Slag treated with percentage of Zycobond

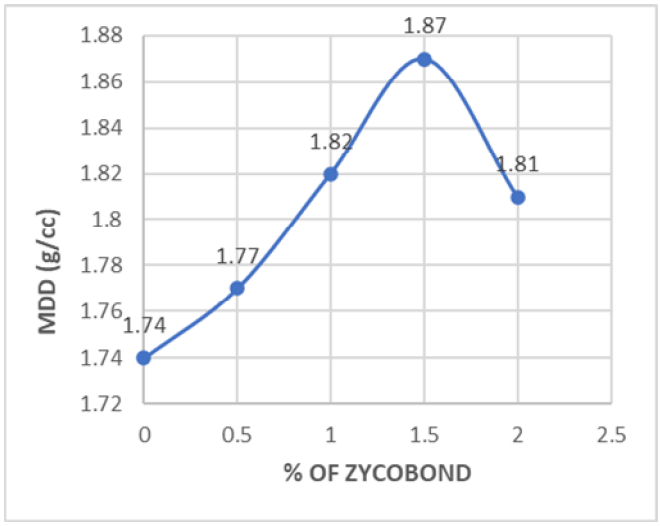


Fig -4: Variation in MDD of Expansive Soil and Copper Slag treated with percentage of Zycobond

D. California Bearing Ratio (CBR) Test

Table -6: Results of CBR test

S.NO	MATERIAL PROPORTION	CBR SOAKED (%)
1	82% ES with 18% CS + 0 %ZB	4.66
2	82% ES with 18% CS + 0.5%ZB	5.78
3	82% ES with 18% CS + 1%ZB	6.94
4	82% ES with 18% CS + 1.5% ZB	8.11
5	82% ES with 18% CS + 2%ZB	7.26

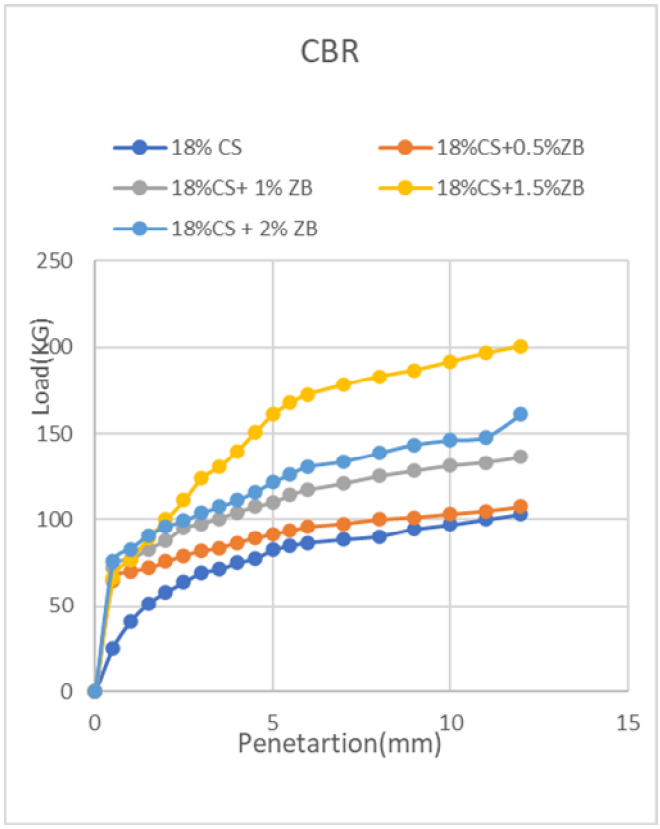


Fig -5: Variation in Compaction curves of Expansive Soil and Copper Slag treated with percentage of Zycobond

E. Triaxial test

Table -7: results of Triaxial test

S.NO	MATERIAL PROPORTION	C(Kg/m^2)	ϕ(º)
1	82% ES with18 % CS + 0% ZB	78.4	4.7
2	82% ES with18 % CS + 0.5% ZB	73.18	5.1
3	82% ES with 18% CS + 1% ZB	69.57	5.8
4	82% ES with 18% CS + 1.5% ZB	64.13	6.5
5	82% ES with 18% CS + 2% ZB	62.25	6.2

Fig -6: Variation in Angle of Internal Friction of Expansive Soil and Copper Slag treated with percentage of Zycobond

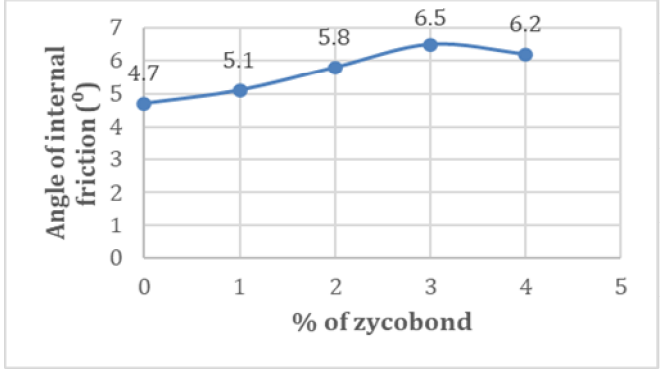
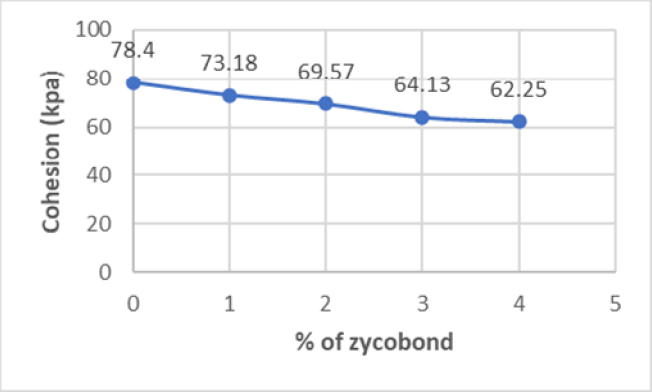


Fig -7: Variation in Cohesion of Expansive Soil and Copper Slag treated with percentage of Zycobond



VI. CONCLUSIONS

The following conclusions were based on the laboratory studies carried out of Copper Slag and Zycobond found through the laboratory on this study. From the laboratory investigations the Optimum percentage research is 18% and 1.5% respectively

Table -7: Optimum Percentages of FS and ZB, observed the laboratory investigations

S.NO	Additives	Optimum percentage addition
1	Copper Slag	18%
2	Zycobond	1.5%

1) It was observed from the laboratory investigations that the addition of 18 % Copper Slag reduced the free swell of the expansive soil by 21 %, while the addition of 3 % Zycobond reduced the free swell of the Copper Slag treated expansive soil by 49.47% to untreated expansive soil.

2) It was noticed from the laboratory investigations that the addition of 18 % Copper Slag reduced the liquid limit of the expansive soil by 11.94%, while the addition of 3 % Zycobond reduced the liquid limit of the Copper Slag treated expansive soil by 22.68% to untreated expansive soil.

3) The laboratory investigations revealed that the plastic limit of the expansive soil Was increased by 26.50% with the addition of 18% CS and the plastic limit of CS treated expansive soil was Increased by 27.62% with the addition of 3 % Zycobond as an optimum when compared to untreated expansive soil.

4) It was observed from the laboratory investigations that the addition of 18% Copper Slag reduced the plasticity Index of the expansive soil by 39.89%, while the addition of 3% Zycobond reduced the plasticity index of the Copper Slag treated expansive soil by 67.09% to untreated expansive soil

5) It was found from the laboratory investigations that the optimum moisture content of the expansive soil has been decreased by 37.17% on addition of 18%% Copper Slag and further the optimum moisture content of Copper Slag treated expansive soil has been decreased by 45.90% with the addition of 3% Zycobond as an optimum when compared with untreated expansive soil.

6) It is observed from the laboratory tests that the OMC of the Expansive soil has been decreased from 28.06% to 17.63% on the addition of 18% CS and it has been further decreased from 17.63% to 15.18% with addition of 1.5% Zycobond.

7) It was found from the laboratory investigations that the maximum dry density of the expansive soil has been improved by 13.21% on addition of 18% Copper Slag and the maximum dry density of Copper Slag treated expansive soil has been improved by 19.25% with the addition of 3% Zycobond as an optimum when compared with untreated expansive soil.

8) It was observed from the laboratory investigations that the Soaked CBR value of the expansive soil has been improved by 71.24% on addition of 18% Copper Slag as an optimum and further the CBR value of Copper Slag treated expansive soil has been Improved by 83.47% with the addition of 3% Zycobond as an optimum when compared with untreated expansive soil.

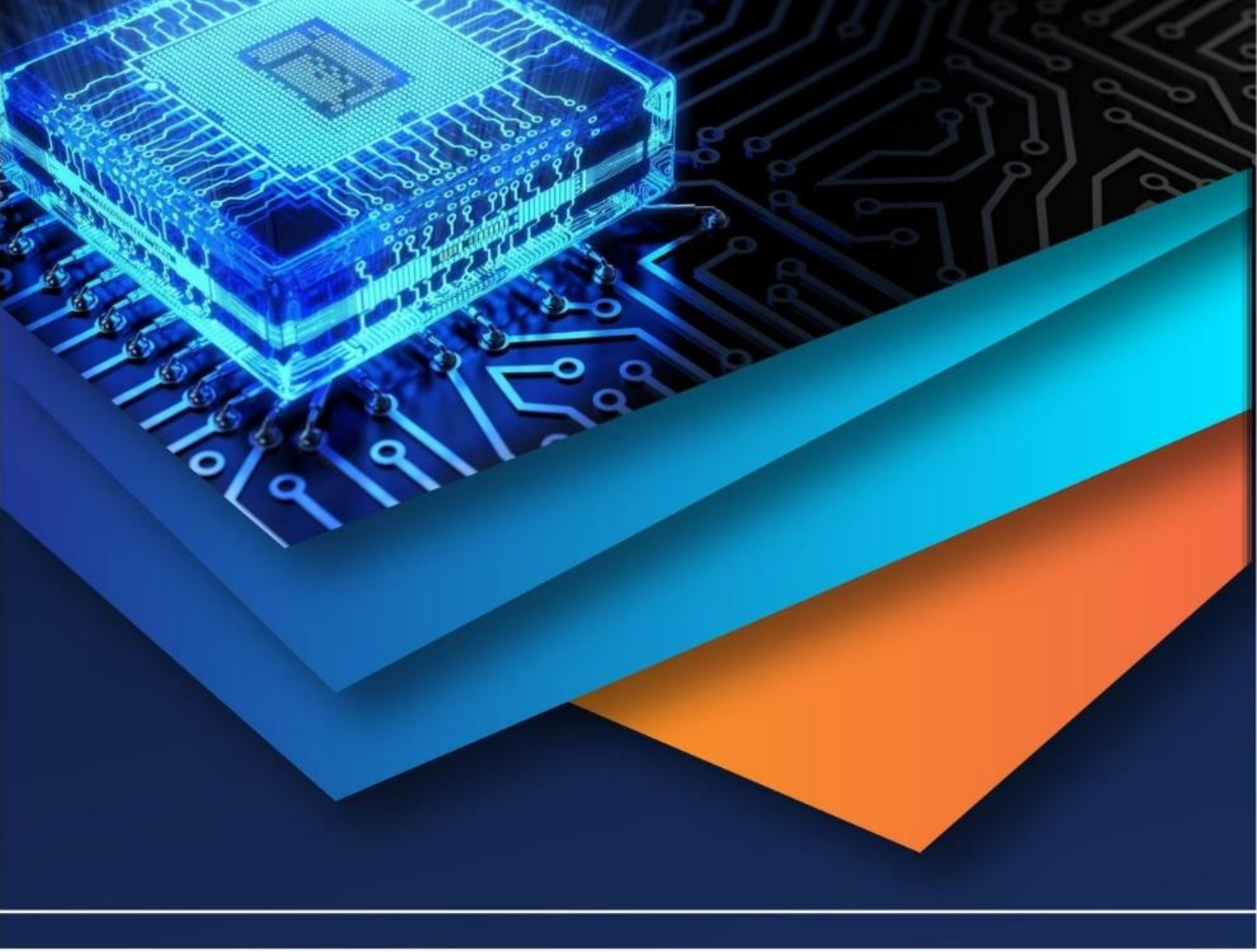
9) It was observed from the laboratory investigations that the cohesion value of the expansive soil has been decreased by 17.82% on addition of 18 %Copper Slag as an optimum and further the value of Copper Slag treated expansive soil has been decreased by 32.78% with the addition of 3 % Zycobond as an optimum when compared with untreated expansive soil.

10) It is observed that the Angle of Internal Friction of the Expansive soil has been increased from 2.4⁰ to 4.7⁰ on addition of 18% CS and it has been further increased from 4.7⁰ to 6.5⁰ with addition of 1.5% Zycobond.

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