iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** XI **Month of publication:** November 2025

DOI: https://doi.org/10.22214/ijraset.2025.75220

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XI Nov 2025- Available at www.ijraset.com

Enhancing the Properties of Expansive Soil Using Copper Slag and Ferric Chloride

Dr. D. Koteswara Rao[1], K. Jahnavi[2]
[1]Professor, Department of Civil Engineering, OSD to Hon'ble Vice Chancellor, JNTUK, Kakinada, Andhra Pradesh, India.
[2]Post graduation Student, Department of Civil Engineering, University College of Engineering(A), JNTUK, Kakinada, Andhra Pradesh, India

Abstract: Expansive soils present a significant geotechnical challenge to pavement infrastructure due to their susceptibility to large volume changes with fluctuating moisture content, a behaviour manifests as differential settlement, cracking, and premature structural failure. While conventional soil stabilization techniques exist, they are often hindered by high costs, complex applications, or environmental concerns. This research, therefore, explores a sustainable and cost-effective alternative by utilizing industrial by-products to enhance the engineering properties of expansive soils. The primary objective is to systematically evaluate the efficacy of incorporating copper slag, in conjunction with ferric chloride, as a stabilization agent. This study assesses the impact of these admixtures on key geotechnical parameters, including Optimum Moisture Content (OMC), Maximum Dry Density (MDD), and California Bearing Ratio (CBR), to determine their suitability for pavement subgrade applications.

Keywords: Expansive Soil, Copper Slag, Ferric Chloride, OMC, MDD, CBR

I. INTRODUCTION

Expansive soils, colloquially known as black cotton soils in India, cover approximately 20% of the nation's landmass, posing a persistent threat to the durability of civil engineering structures. Found extensively across the Deccan Plateau, these soils are geotechnically problematic due to their mineralogical composition, which is rich in montmorillonite. The presence of this clay mineral imparts a high shrink-swell potential, causing significant volumetric changes in response to seasonal moisture variations. During wet periods, the soil swells, and during dry periods, it shrinks, which often leads to the formation of deep cracks. This cyclical movement exerts immense pressure on overlying structures, leading to severe damage in pavements, building foundations, and canal linings. To mitigate these adverse effects, various ground improvement techniques have been developed. These range from mechanical methods, such as soil replacement and pre-wetting, to chemical stabilization using traditional binders like cement and lime. However, the production of these conventional stabilizers is energy-intensive and contributes to notable carbon emissions. Consequently, recent research has shifted towards the utilization of sustainable and cost-effective industrial by-products as alternative stabilization materials. Researchers such as Lavanya et al. (2017) and Mohamed A. Sakr et al. (2021) have successfully demonstrated the potential of various waste materials to improve the properties of expansive soils. Despite these advancements, a research gap exists in understanding the synergistic effect of combining metallurgic slag with chemical activators for soil stabilization. While materials like fly ash and rice husk ash have been studied extensively, there is a comparative scarcity of research on the combined application of copper slag-a by-product of copper smelting- and ferric chloride.

II. OBJECTIVES OF THE STUDY

1) Determine the fundamental properties of the Expansive soil.
2) Investigate the impact of varying Copper Slag percentages (13%, 14%, 15%, 16% and 17% by dry weight of soil) on the soil's strength characteristics.
3) Identify the optimum Copper Slag dosage required to achieve the maximum soil strength.
4) Assess the effect of varying Ferric Chloride dosages (0.5%, 1%, 1.5%, and 2% by dry weight of soil) on the soil's strength properties.
5) Find the optimum dosage of Ferric Chloride, in combination with Copper Slag to achieve the maximum overall soil strength.

III. LITERATURE REVIEW

Amit Kumar Jangid et al. (2023)done an experimental investigation of mechanical properties of problematic expansive soil using copper slag and its statistical validation. Here copper slag has been added to the soil from 5-30% at a 5% variation by its oven-dry weight. The experimental results reveal that the free swell index of soil has decreased by 69.88% with the additionof 30% copper slag.

Mohamed A. Sakr et al. (2021) carried out a study on Enhancing the Swelling Characteristics and Shear Strength of Expansive Soil Using Ferric Chloride Solution. Here the free swell index and the swelling pressure of the expansive soil treated with ferric chloride decreased by 62% and 43%. Ferric chloride solution can be considered as an effective and economical additive to improve the characteristics of swelling soils in arid environment.

Mannat Jandial et al. (2020) studied on soil stabilization by using Fly Ash and Ferric Chloride. Here they recommended by the addition of 1.5 % of ferric chloride, the unconfined compressive strength (UCS) of the stabilized subgrade soil is expanded when contrasted with the subgrade soil. With the variation of ferric chloride more than 1.5% optimum moisture content of the black cotton soil is expanded while the most extreme dry density of soil reduced.

H. Venkateswarlu et al. (2019) studied on the Strength Behaviour of Expansive Soil Treated with Quarry Dust and Ferric Chloride. carried out different tests such as compaction, specific gravity and CBR in the laboratory on expansive clays with different proportions of quarry dust by dry weight. From the test results addition of 5% quarry dust is mixed with different % of $FeCl_3$ (i.e. 0, 0.5, 1, 1.5 & 2%) to BC soil increases its OMC, decreasing its MDD, increased CBR of soil by the addition 5% quarry dust and further decrease.

D. Koteswara Roa et al. (2018) carried out A Laboratory study on the performance of Expansive soil subgrade treated with Seashell Powder and Ferric chloride. It was observed from the laboratory test results that the liquid limit of the BC soil has been improved by 47.3% on the addition of 10% Sea shell powder when compared with the untreated BC soil and further upon adding 1.5% $FeCl_3$ the liquid limit increased by 41.59%. The plasticity index was improved by 67.39% on adding 10% SSP and further improved by 26.35% on adding 1.5 % $FeCl_3$. OMC was improved by 13.06% on adding 10% SSP and further improved by 3.904% on adding 1.5% $FeCl_3$. MDD increased by 15.86% on adding 10% SSP and further increased by 5.95% on adding 1.5% $FeCl_3$. CBR value increased by 50% 10% SSP and further increased by 53.006% on adding 1.5% $FeCl_3$.

P. Rajendra Kumar et al. (2017) carried out a laboratory study of black cotton soil blended with copper slag and fly-ash. With increase in 5% to 30% of Copper Slag, Dry density increases from 1.46 to 2.06. The % increase in dry density is 48% and with increase in % of Copper Slag, Unsoaked CBR value increases from 1.86 to 16.66 indicating the increase of CBR value up to 495%. With increase in % of Copper Slag, Soaked CBR value increases from 1.80 to 6.32 indicating the increase of CBR value up to 67%.

C. Lavanya et al. (2017) studied on the Swelling Potential of Copper Slag Cushion Laid Over Expansive Soil Bed. copper slag is similar to that of medium sand and it can be used as a construction material in place of sand. Copper slag, along with an admixture, can be used as an alternative material to sand in road construction. Here lime is used as admixture, lime is more efficacious in reducing heave compared to cement when added to copper slag.

IV. METHODOLOGY

A. Overview of Experimental Program

The experimental investigation was carried out in several distinct stages to systematically evaluate the efficacy of Copper Slag (CS) and Ferric Chloride ($FeCl_3$) as dual-stabilizers for enhancing the properties of expansive soil. The overall procedure encompassed the characterization of raw materials, optimization of stabilizer dosages, preparation and curing of stabilized soil mixtures, and comprehensive laboratory testing, followed by the analysis of results.

B. Materials Characterization

1) Expansive Soil

The expansive soil was collected from a 1.5m depth in Yanamadala, Ramachandrapuram, Dr. B.R. Ambedkar Konaseema district, Andhra Pradesh and classified according to the Unified Soil Classification System (USCS). Initial geotechnical properties of the raw soil were determined, including particle size distribution, Atterberg limits (Liquid Limit, Plastic Limit, Shrinkage Limit), specific gravity, Free Swell Index (FSI), and Compaction parameters (Maximum Dry Density, MDD, and Optimum Moisture Content, OMC), following relevant ASTM/IS standards.

2) Stabilizing Agents

- *Copper Slag (CS):* Granulated copper slag, a by-product from the National Enterprises, Faridabad, Haryana was procured, dried, and sieved to be used as a replacement material. The CS was incorporated into the expansive soil matrix as a partial replacement by dry weight of the soil.

Fig-1: Copper Slag

- *Ferric Chloride ($FeCl_3$):* Anhydrous Ferric Chloride, a chemical additive, was used in solution form. It was dissolved in the mixing water to ensure uniform distribution throughout the soil-slag matrix.

Fig-2: Ferric Chloride

C. Mix Proportioning and Sample Preparation

The stabilization program involved two phases: Initial stabilization with Copper Slag and secondary chemical activation with Ferric Chloride.

Copper Slag Variation: The expansive soil was replaced with varying percentages of Copper Slag, typically ranging from 13% to 17% of the dry weight of the soil.

Ferric Chloride Variation: For the optimum CS content determined from preliminary tests (e.g., Atterberg Limits and FSI), Ferric Chloride was introduced at dosages ranging from 0.5% to 2.0% of the dry weight of the stabilized mix.

D. Laboratory Testing Program

The performance evaluation of the stabilized expansive soil was conducted through the following key geotechnical tests.

1) *Atterberg Limits Test:* This test was performed to determine the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) of both untreated and stabilized soil samples, following IS 2720 - Part 5. The variation in plasticity characteristics helped in assessing the reduction in swelling tendency and improved workability of the soil, as a reduction in PI indicates a decrease in the thickness of the diffused double layer and subsequent particle flocculation.
2) *Differential Free Swell (DFS) Test*: The free swell behavior of the untreated and treated soil was studied to evaluate the reduction in expansiveness after stabilization, according to IS 2720 - Part 40. The DFS value was obtained by immersing oven-dried soil samples in kerosene and distilled water separately, and calculating the difference in swell percentage. This test was particularly important in determining the effectiveness of stabilization in controlling volumetric changes.
3) *Modified Proctor compaction test:* Compaction tests were conducted to establish the maximum dry density (MDD) and optimum moisture content (OMC) for each mix proportion, following IS 2720 - Part 7. The test was performed to determine the optimal moisture content and energy required for maximum densification.

4) *California Bearing Ratio (CBR) Test:* The load-bearing capacity of the stabilized soil for pavement applications was determined using the CBR test, conducted as per IS 2720 - Part 16. Both soaked (4-day immersion) and unsoaked tests were conducted to provide a measure of the potential application of the stabilized soil in pavement subgrade construction. The CBR values at 2.5 mm and 5.0 mm penetration were calculated, and the higher value was reported.

V. RESULTS AND DISCUSSION

Table-1: Properties of Untreated Expansive Soil

S.NO	Property	Expansive Soil
1	Particle size distribution	
	Sand (%)	5.86
	Silt (%)	14.23
	Clay (%)	79.91
2	Atterberg's limit	
	Liquid limit (%)	81.7
	Plastic limit (%)	38.84
	Plasticity Index (%)	42.85
3	Modified compaction results	
	Optimum moisture content (%)	28.47
	Maximum dry density (g/cc)	1.54
4	Differential free swell (%)	100
5	Specific Gravity	2.5
6	IS Classification	CH
7	California bearing ratio, CBR (%)	1.74
8	Cohesion, c (kN/m^2)	97.71
9	Angle of internal friction, F (°)	2.1

A. *Differential free swell*

Table -2: Results of Free swell index test

S.NO	Mix proportions	DFS (%)
1	85%ES + 15%CS + 0%$FeCl_3$	40
2	84.5%ES + 15%CS + 0.5%$FeCl_3$	20
3	84%ES + 15%CS + 1%$FeCl_3$	15
4	83.5%ES + 15%CS + 1.5%$FeCl_3$	10
5	83%ES + 15%CS + 2%$FeCl_3$	5

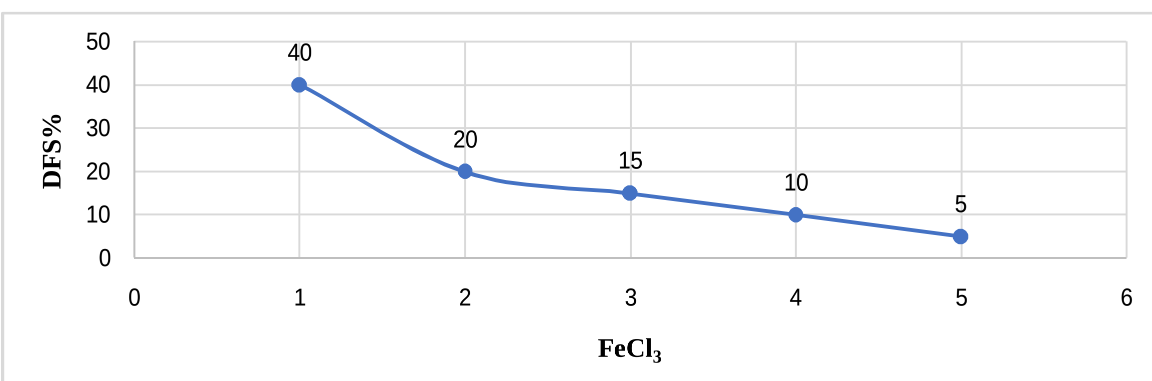


Fig -3: Variation in DFS of Expansive Soil and Copper Slag treated with percentage of Ferric Chloride ($FeCl_3$)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XI Nov 2025- Available at www.ijraset.com

B. *Atterberg's Limit Test*

Table -3:Results of Atterberg's Limit Test

S.NO	Mix proportions	LL (%)	PL (%)	PI (%)
1	85%ES + 15%CS +0%$FeCl_3$	61	28.72	32.27
2	84.5%ES + 15%CS +0.5%$FeCl_3$	44.13	26.7	17.42
3	83%ES + 15%CS +1%$FeCl_3$	41.86	25.61	16.24
4	83.5%ES + 15%CS +1.5%$FeCl_3$	37.6	23.86	13.73
5	83%ES + 15%CS +2%$FeCl_3$	34.2	22.1	12.1

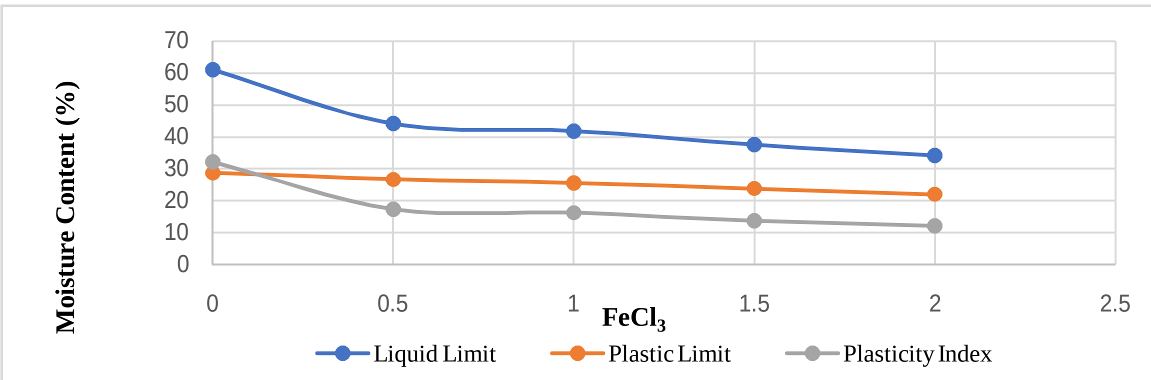


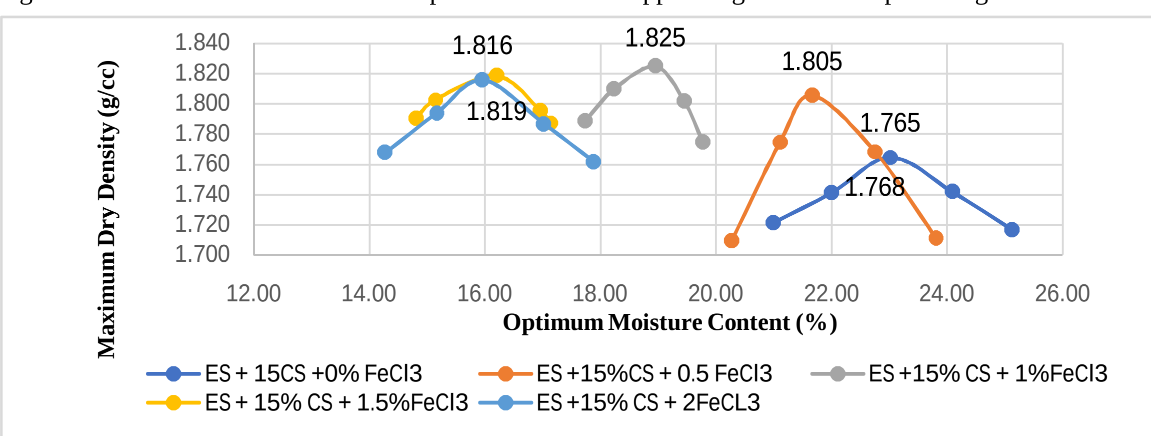
Fig -4: Variation in LL, PL & PI of Expansive soil and Copper Slag treated with percentage of Ferric Chloride

C. *Standard Proctor Compaction Test*

Table -4: Results of Modified compaction test

S. NO	Mix proportions	OMC(%)	MDD(%)
1	85%ES + 15%CS + 0%$FeCl_3$	23.02	1.765
2	84.5%ES + 15%CS + 0.5%$FeCl_3$	21.67	1.805
3	84%ES + 15%CS + 1%$FeCl_3$	18.95	1.825
4	83.5%ES + 15%CS + 1.5%$FeCl_3$	16.21	1.819
5	83%ES + 15%CS + 2%$FeCl_3$	15.96	1.816

Fig -5: Variation in OMC & MDD of Expansive Soil and Copper Slag treated with percentage of Ferric Chloride



ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XI Nov 2025- Available at www.ijraset.com

D. California Bearing Ratio (CBR) Test

Table -5: Results of CBR test

S.NO	Mix proportions	CBR (%)
1	85%ES + 15%CS + 0%$FeCl_3$	4.12
2	84.5%ES + 15%CS + 0.5%$FeCl_3$	7.61
3	84%ES + 15%CS + 1%$FeCl_3$	9.05
4	83.5%ES + 15%CS + 1.5%$FeCl_3$	8.42
5	83%ES + 15%CS + 2%$FeCl_3$	7.97

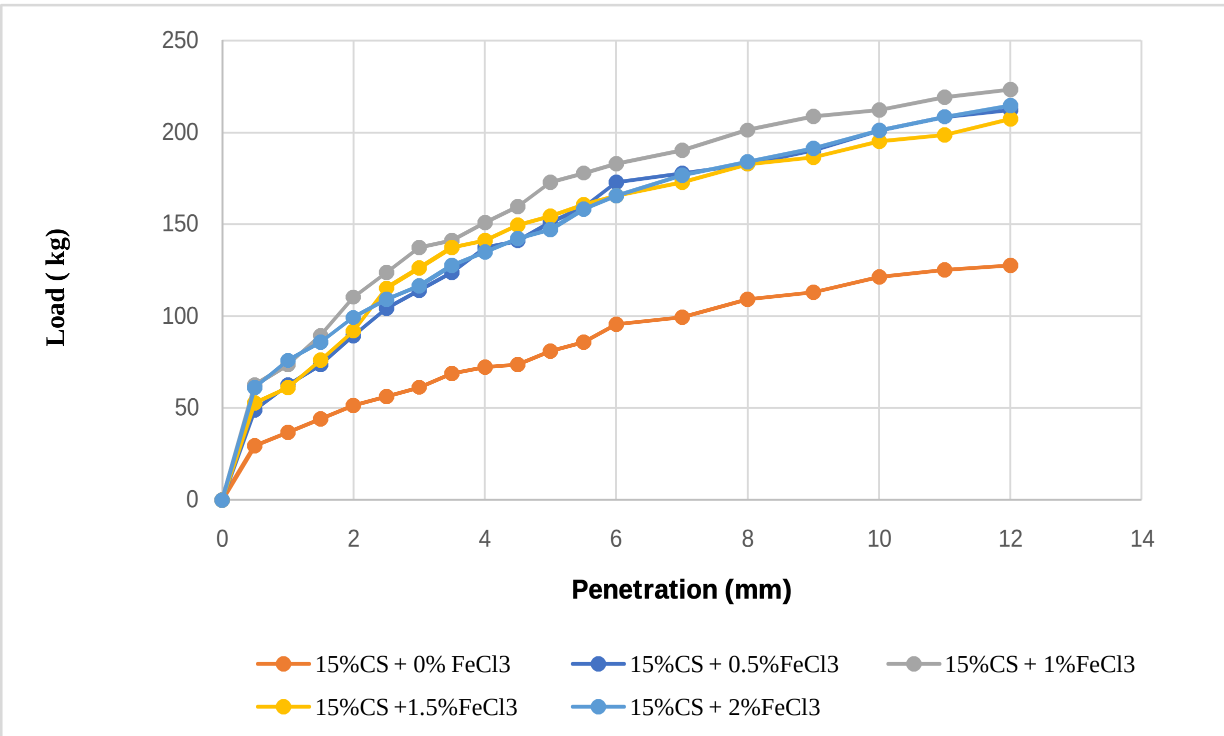


Fig -6: Variation in Compaction curves of Expansive Soil and Copper Slag treated with percentage of Ferric Chloride

Table-6: Laboratory test results of Untreated and Treated Expansive Soil with 15% Copper Slag and 1% Ferric Chloride

S.NO	Properties	Symbol	Expansive Soil	85% ES + 15%CS	84%ES + 15%CS 1%$FeCl_3$
1	Liquid Limit (%)	W_L	81.7	61	41.86
2	Plastic Limit (%)	W_P	38.84	28.72	25.61
3	Plasticity Index (%)	I_P	42.85	32.27	16.24
4	IS Classification		CH	CH	CI
5	Differential Free Swell (%)	DFS	100	40	10
6	Optimum Moisture Content (%)	OMC	28.47	23.02	18.95

7	Maximum Dry Density (g/cc)	MDD	1.54	1.765	1.825
8	California Bearing Ratio (%)	CBR	1.74	4.12	9.05
9	Angle of internal friction (°)	F	97.71	85.23	65.42
10	Cohesion (kN/m^2)	c	2.1	3.4	6.7

VI. CONCLUSION

The following conclusions were drawn based on the laboratory studies of Copper Slag and Ferric Chloride obtained for this study. From the laboratory investigations, the Optimum percentages identified were 15% for Copper Slag (CS) and 1% for Ferric chloride ($FeCl_3$) respectively.

1) The Differential Free Swell (DFS) was reduced by 60% with 15% CS and showed a total reduction of 85% upon the inclusion of 1% $FeCl_3$.
2) The Liquid limit (LL) of the untreated Expansive soil (ES) showed a significant improvement of 25.34% following the incorporation of CS. A further increase of 48.76% was observed when 1% $FeCl_3$ was subsequently added to the CS-treated soil.
3) The plasticity index (PI) demonstrated a substantial increase of 24.47% with the addition of 15% CS, which was further enhanced by 62.10% upon the inclusion of 1% $FeCl_3$.
4) The Optimum Moisture Content (OMC) improved by 19.29% with 15% CS treatment, with an additional33.43% improvement following the inclusion of 1% $FeCl_{3.}$
5) The Maximum Dry Density (MDD) improved by 14.61% with 15% CS treatment,18.50% with an additional improvement following the inclusion of 1% $FeCl_{3.}$
6) The California Bearing Ratio (CBR) value improved by 136.78% with 15% CS and was significantly boosted by an additional 420.11% when 1% $FeCl_3$ was introduced
7) The Specific Gravity of the soil improved by 4.58% with the 15% CS and showed a cumulative increase of 9.2% with the final addition of 1% $FeCl_3$.

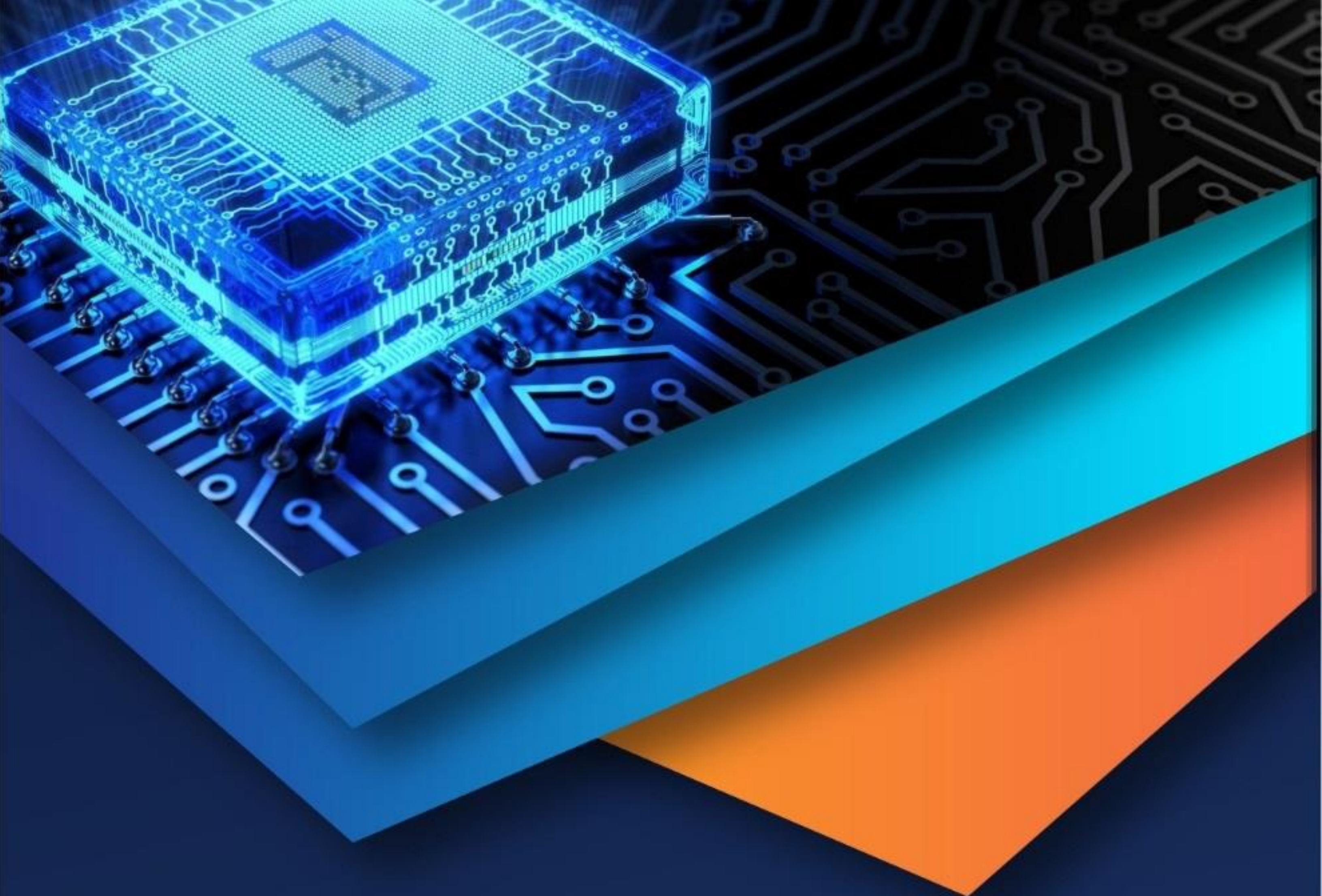
The synergic combination of 15% Copper Slag and 1% Ferric Chloride significantly optimized the geotechnical properties of the air-dried Expansive soil. This stabilization treatment renders the soil suitable for use as a pavement subgrade material, conforming to the requirements outlined in the relevant IRC Codes of Practice

VII. VIABILITY

As per IRC 37-2012, a minimum CBR value of 8% is mandatory for subgrade soil in flexible pavements. In this study, the Expansive Soil treated with 15% Copper slag and 1% Ferric Chloride achieved a CBR of 9.05%. This result confirms the suitability of the treated Soil as a subgrade material in compliance with the IRC standards

REFERENCES

[1] Amit Kumar Jangid, Kamaldeep Singh Grover (2023) “Experimental investigation of mechanical properties of problematic expansive soil using copper slag and its statistical validation”.
[2] Mohamed A. Sakr et al. (2021) “Enhancing the Swelling Characteristics and Shear Strength of Expansive Soil Using Ferric Chloride Solution”.
[3] H. Venkateswarlu et al. (2019) “Strength Behaviour of Expansive Soil Treated with Quarry Dust and Ferric Chloride”. Ground Improvement Techniques and Geosynthetics, Lecture Notes in Civil Engineering 14.
[4] C. Lavanya et al. (2017) “Study of Swelling Potential of Copper Slag Cushion Laid Over Expansive Soil Bed”.
[5] Mohan chand et al. (2017) “Behavior of black cotton soil with addition of copper slag and steel slag”. International Research Journal of Engineering and Technology (IRJET), e-ISSN:2395-0056, p-ISSN: 2395-0072, Volume:04 Issue: 01 Jan-2017
[6] Mohammed A. Qureshi et al. (2015) “Improvement in soil properties of Expansive Soil by using Copper Slag”. International Journal of advance Research in Engineering, Science & Technology (IJAREST), ISSN(O):2393-9877, ISSN(P): 2394-2444, Volume 2, Issue 7, July- 2015
[7] D. Koteswara Rao, S. Vineela (2017): “A laboratory study oh the performance of expansive soil subgrade treated with Seashell powder and Ferric Chloride”.
[8] P. Venkata Muthyalu et al. (2012) “Performance of chemically stabilized expansive soil”.
[9] IS: 2720 part- 4 (1975): Grain size analysis.
[10] IS: 2720 part-40 (1977): Determination of Free Swell Index.
[11] IS: 2720 part-3 (1980): Determination of Specific gravity.
[12] IS: 2720 part- 5 (1985): Determination of Liquid limit and Plastic limit.
[13] IS: 2720 part- 8 (1983): Determination of Dry density and Optimum moisture content.
[14] IS: 2720 Part-16 (1979): Determination of California bearing ratio.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY