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Geo-Mechanical and Environmental Evaluation of Residual Lateritic Soil Stabilized with Coal Ash and Calcium Oxide

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ABSTRACT: This analyses examines the stabilization of residual lateritic soil using coal ash (CA) and calcium oxide (CaO), addressing both engineering evaluation and environmental impact. Laboratory tests evaluated the influence of these additives on plasticity, compaction behavior, unconfined compressive strength (UCS), and leaching potential. The results revealed significant improvements in geotechnical characteristics, with optimum performance at 35% CA and 4% CaO. The findings support the dual benefits of enhanced soil behavior and safe reuse of industrial byproducts. coal ash, a byproduct of thermal power plants, remains a worldwide concern due to the ongoing need for effective disposal solutions. Its role in triggering pozzolanic reactions has long been recognized and is currently a key zones of interest for researchers exploring its potential as a soil stabilization admixture. Efforts are underway to investigate how soils from different regions respond when mixed with coal ash alone or combined with other additives, aiming to enhance their parameters while maximizing the use of this waste materials.

KEYWORDS: Coal ash, lateritic soil calcium oxide, compaction, UCS, environmental safety, stabilization.

I. INTRODUCTION

Residual lateritic soils, prominent in tropical areas, face engineering limitations like high plasticity and strength degradation in wet conditions. Simultaneously, coal ash a byproduct of thermal power plants poses disposal difficulties. While coal ash and lime have been individually studied for soil stabilization, their combined impact on residual lateritic soil remains underexplored. This study investigates the synergistic role of CA and CaO in enhancing soil properties. Residual lateritic soils, widely used in tropical regions for constructing pavement, embankments, and foundations, face geotechnical challenges such as poor workability, compaction difficulties, and strength loss, limiting their optimal use. Concurrently, coal ash, a byproduct of thermal power plants, poses meaningful disposal challenges worldwide, despite its potential as a pozzolanic material for soil stabilization. While coal ash and additives like calcium oxide have been studied for improving various soils, there is a notable gap in understanding their combined effects on residually derived lateritic soil.

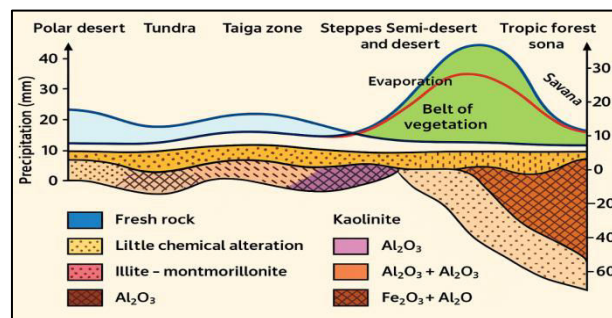
II. LITERATURE SURVEY

The stabilization of residual lateritic soils has been a focal point in geotechnical engineering, particularly in tropical regions where these soils are prevalent. Below is a review of key studies relevant to the investigation of residual lateritic soil stabilization using coal ash (CA) and calcium oxide (CaO), Kaneeraj & Gaayathri [1]: In their research published in the Journal of Geotechnical and Geoenvironmental Engineering (JGGE), the authors explored the soil mechanics characteristics of fly ash-soil mixes. They demonstrated that fly ash, a component of coal ash, enhances soil strength and reduces plasticity, laying foundational insights for the use of coal ash in soil stabilization. Their findings highlight the pozzolanic properties of fly ash, which contribute to improved engineering behavior. Koolias et al. [2]: Published in Soils & Foundations, this work investigated the strength of fine-grained soils stabilized with lime and ash. The study confirmed that lime, similar to CaO, induces flocculation and pozzolanic reactions, significantly boosting soil strength and stability. This supports the combined use of coal ash and calcium oxide, as explored in the current research, for enhanced geotechnical performance. Misra et al. [3]: This study, featured in the International Journal of Geotechnical Engineering (IJGE), examined the geotechnical properties of stabilized alluvial soil. The authors found that industrial byproducts like ash can improve compaction and strength characteristics, offering a sustainable approach

to soil stabilization. Their results are relevant to the use of coal ash for lateritic soils, though regional soil variations necessitate further exploration. Kundu et al. [4]: Published in the Journal of Hazardous Materials (JHazardMat), this research analyzed the mechanical and leachate behavior of stabilized soil. The study emphasized the environmental safety of using coal ash, noting minimal leaching risks when properly mixed with additives. This aligns with the current study's focus on balancing engineering benefits with environmental considerations. Thaapa et al. [5]: Presented at the Geo-Environment International Conference (GEInt Conf), this work investigated coal ash and lime stabilization of Himalayan soil. The findings revealed significant improvements in strength and durability, particularly with optimal ash-lime combinations. These results provide a comparative basis for the current study's exploration of CA and CaO in tropical lateritic soils.

The literature collectively underscores the potential of coal ash and calcium-based additives for soil stabilization, yet a gap remains in understanding their synergistic effects on residual lateritic soils. This study by Meshram and Prasad addresses this by combining CA and CaO, leveraging pozzolanic reactions and flocculation to enhance geotechnical properties while promoting sustainable reuse of industrial byproducts.

III. MATERIALS AND METHODS



Materials Used: Residual lateritic soil was sourced from Raisen Road, Bhopal. Class F coal ash was procured from the Sarni Thermal Power Plant, and high-purity CaO was used as an additive.

Experimental Setup: The investigation focused on Atterberg limits, compaction (Standard Proctor), UCS, and CU triaxial tests. Soil samples were prepared with CA proportions of 20%, 35%, and 50%, and CaO additions of 2–4%. All tests followed IS 2720 standards.

A successive re-compaction technique was applied to assess the impact of particle rearrangement on strength and density.

III. RESULTS AND DISCUSSION

A. Plasticity Behavior

The addition of CA marginally reduced the liquid and plastic limits. CaO further decreased the plasticity index (PI), indicating successful flocculation and pozzolanic reactions. Maximum PI reduction occurred at 35% CA and 3% CaO.

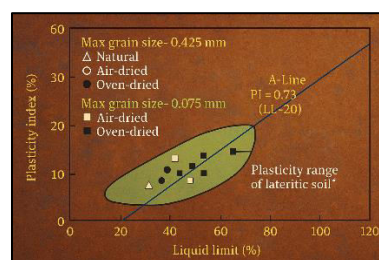


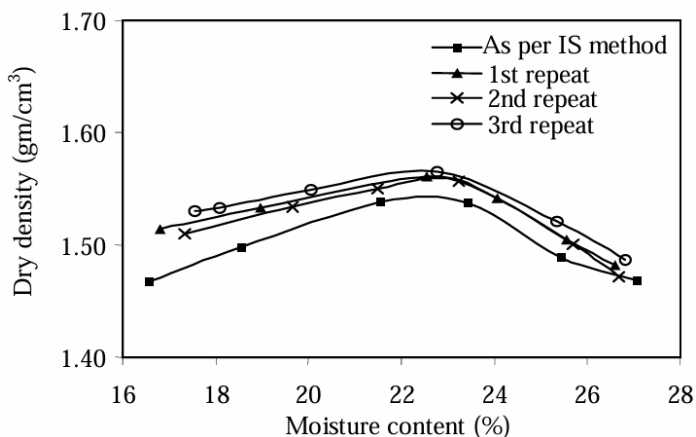
Figure1: Effect of worldwide environment on the degree of weathering and associated by products

Table1: Overview of plasticity variation in tests soil caused by CaO addition at various condition timing.

Calcium Oxide Addition %	Liquid Limit %			Plastic Limit %			Plasticity Index %		
	1day	28days	56days	1day	28days	56days	1day	28days	56days
0	54.9	54.7	54.8	37.5	37.3	37.6	17.4	17.3	17.2
1	52.1	---	---	39.4	---	---	12.1	---	---
2	50.1	50.3	50.5	40.2	42.3	42.6	9.9	8.0	7.9
3	50.1	---	---	40.7	---	---	9.5	---	---
4	50.3	51.0	51.2	41.3	43.5	44.8	9.0	7.5	7.3
5	50.3	---	---	41.3	---	---	8.9	---	---
8	50.2	51.1	51.5	41.4	43.9	45.2	8.8	7.2	6.0

B. Compaction Characteristics

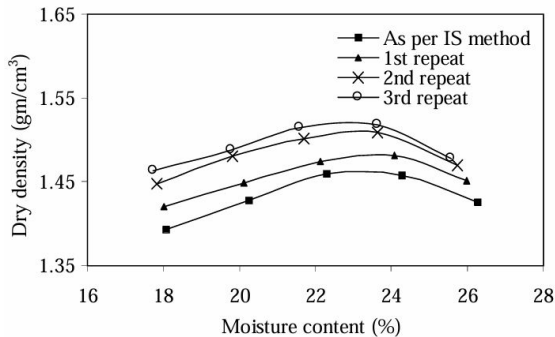
Optimal moisture content (OMC) decreased while maximum dry density (MDD) increased with rising CaO levels. 35CA + 4% CaO showed the best densification. Re-compaction tests confirmed enhanced packing and particle rearrangement.



(a)

Mix Designation: 20CA

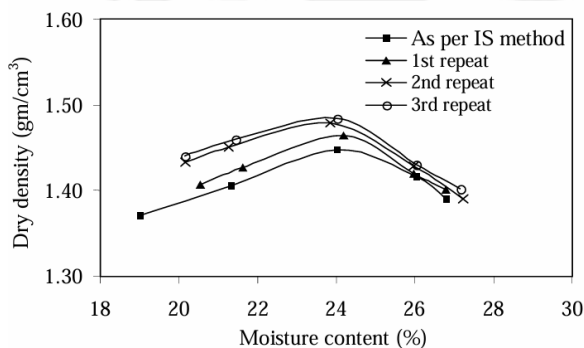
Calcium Oxide content - Nil



(b)

Mix Designation: 35CA

Calcium Oxide content - Nil



(c)

Mix Designation: 50CA

Calcium Oxide content - Nil

Figure2: Impact of repeated compaction on dry density vs. moisture content relationship of various soil coal ash mixture without addition of calcium oxide

C. Unconfined Compressive Strength (UCS)

UCS values improved significantly with CaO, especially for 35% CA mixes. After 56 days, the 35CA + 4% CaO sample displayed over 250% strength gain compared to untreated soil.

Table2: UCS and failure strains for different soil coal ash mixture with no calcium oxide adding

Curing timing (Days)	20CA mix		35CA mix		50CA mix	
	σ_{ucf}	ξ_{ucf}	σ_{ucf}	ξ_{ucf}	σ_{ucf}	ξ_{ucf}
0	360.9	3.06	296.2	2.06	129.4	3.61
3	391.3	2.83	303.0	1.78	133.4	2.70
7	433.5	3.56	295.2	1.85	135.3	2.42
14	488.4	3.34	304.0	2.15	141.2	2.38
28	494.3	3.20	324.6	1.91	148.1	2.19
56	533.5	3.29	338.3	1.91	153.0	2.19

480	557.0	2.88	389.3	1.78	165.7	2.34
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D. Shear Strength Behavior

Triaxial test results revealed an increase in internal friction angle from 38.6° (2% CaO) to 44.9° (4% CaO), indicating denser packing and improved antiparticle bonding.

Table3: Details of consolidated undrained triaxial testing

Series	Test no.	Mix	Lime added (%)	Test/Compaction condition	Dry unit weight (gm/cm ³)	Moisture content (%)
1	1-3	BFA	Nil	Optimum moisture	1.23	28.30
2	4-6	RLS	Nil	Undisturbed	1.28	27.66
	7-9			Remoulded at field density	1.28	27.66
	10-12			Compacted at MDD	1.52	25.12
3	13-15	35FA	Nil	Optimum moisture	1.46	23.21
4	16-18	35FA	2	Optimum moisture Dry side of optimum	1.37	27.33
	19-21	35FA	2		1.34	24.10
	22-24	35FA	2	Wet side of optimum	1.34	29.60
5	25-27	35FA	4	Optimum moisture Dry side of optimum	1.34	28.51
	28-30	35FA	4		1.31	22.98
	31-33	35FA	4	Wet side of optimum	1.31	30.52

IV. CONCLUSION

The combined application of coal ash and calcium oxide is an effective strategy to enhance the engineering behavior of residual lateritic soils. A mix of 35% CA and 4% CaO provides optimal strength, compaction, and durability with minimal environmental risk. This method promotes sustainable infrastructure development and coal ash reuse in tropical regions.

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