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EVALUATING THE IMPACT OF CEMENT AND RICE HUSK ASH ON THE STABILIZATION OF LOW BEARING CAPACITY SILTY-CLAYEY SOIL

Ugochukwu T. Ernest[1], Amu O. Oludolapo[1], Olaniyan Amos M.[2] and Emmanuel C. Chukwu[3]

[1]*Department of Civil Engineering, Faculty of Engineering, Federal University Oye-Ekiti, Ekiti State, Nigeria.*

[2]*Department of Agricultural and Bio-Resources Engineering, Faculty of Engineering, Federal University Oye-Ekiti, Ekiti State, Nigeria.*

[3] *Department of Geology, Faculty of Science, Federal University Oye-Ekiti, Ekiti State, Nigeria.*

Abstract

Electrical and electronic waste (E- waste) is applied to electrical and electronic waste materials of all kinds, which includes but not limited to refrigerators, mobile phones, computers, televisions and other electronic gadgets. This E-waste has been found to have tremendous deterioration on engineering properties of soil over time. This study investigates the influence of Cement and Rice Husk Ash (RHA) on some geotechnical properties of E-waste such as the California Bearing Ratio (CBR), triaxial test results, and Unconfined Compressive Strength (UCS). E- Waste contaminated soil samples were treated with 0%, 2%, 4%, 6%, 8%, and 10% cement and RHA. The results of the CBR showed highest value of 59.05%, deviation. stress $\boldsymbol{\sigma^3}$ *peak value of 615.05KN/m*^{2} *and UCS highest value of 276.84 kPa. These results were obtained at the optimal cement-RHA admixture performance. The result demonstrates that the addition of cement and RHA enhances the e-waste soil's engineering properties.*

Keywords: *Electrical and Electronic Waste (E-Waste), Rice Husk Ash (RHA), California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), Triaxial Test.*

Introduction

The increasing generation of electrical and electronic waste (e-waste) has become a very pressing environmental concern all over the word as a result of its hazardous nature due to the presence of heavy metals and toxic chemicals which leaches into the soil and results to severe degradation of its environment and potential negative impacts on soils engineering properties as a result of improper disposal. In Nigeria, traditional disposal methods are used and it is inadequate in preventing e-waste contamination on the surrounding soils. This has necessitated for stabilization of the contaminated soil using cement and Rice Husk Ash (RHA). Cement is a well-known soil stabilizing materials. Ghosh, A *et al*., (2007), but it's expensive to use in soils stabilization project. On the other hand, RHA an agricultural by product of rice milling offers a sustainable alternative that can improve soil properties for road construction and civil engineering works when used in combination with cement Basha, E. A *et al*., (2005). Rhis method not only reduces the leachability of harmful, Cement also increases the pH of the soil, causing the precipitation of certain heavy metals as insoluble hydroxides, further reducing their leachability. Several studies have demonstrated the efficacy of cement in stabilizing soils contaminated with heavy metals, including lead, cadmium, and chromium. For instance, Conner and Hoeffner (1998) found that the use of Portland cement could significantly reduce the leachability of heavy metals in contaminated soils. In the context of e-waste, cement can effectively bind and immobilize metals found in electronic components, such as lead from CRT monitors, cadmium from batteries, and copper from wiring. Furthermore, the high cost of cement, which is generally used as binder, has led to the search for natural materials as either alternative or complement. Studies on alternatives or complements to cement has so far centered on the partial replacement of cement with different materials. RHA is a pozzolanic material, rich in amorphous silica, which reacts with calcium hydroxide in the presence of water to form additional C-S-H, enhancing the strength and durability of the cement matrix.

Zain, M. F. M *et al*., (2004). When used in combination with cement, RHA not only reduces the amount of cement needed (thus lowering CO_2 emissions) but also contributes to the long-term strength development of the stabilized material. Ganesan, K., *et al*., (2008)). Studies have shown that RHA improves the mechanical properties and durability of stabilized soils. The stabilization process of e-waste soils using cement and RHA involves both chemical and physical mechanisms. This research focused on reducing the porosity and permeability on the e-waste contaminated soil sample by utilizing the coagulation properties of cement and RHA. The coagulation process also helped to demobilize the heavy metals. Several studies have evaluated the performance of cement and RHA in stabilizing soils contaminated with e-waste. Olufowobi *et al*. (2014) demonstrated that the addition of 10% RHA and 6% cement to e-waste soil improved its UCS significantly over a curing period. CBR values increase with the addition of cement and RHA, indicating better subgrade support for infrastructure. Makusa (2013) reported similar findings, with cement and RHA improving the geotechnical properties of contaminated soils. The leachability of heavy metals is significantly reduced when e-waste soils are treated with cement and RHA. Mali *et al*. (2012) showed that the combination of cement and pozzolanic materials like RHA could immobilize heavy metals such as lead and cadmium in contaminated soils. The use of RHA as a supplementary cementitious material offers environmental benefits by reducing the amount of cement needed for stabilization. The stabilization of e-waste soils using cement and RHA presents a viable solution to the environmental challenges posed by e-waste contamination. Cement provides the necessary strength and encapsulation properties, while RHA enhances the pozzolanic reactions and reduces the environmental impact of the process. While challenges remain, the combination of cement and RHA holds great promise for sustainable soil stabilization in regions affected by e-waste pollution.

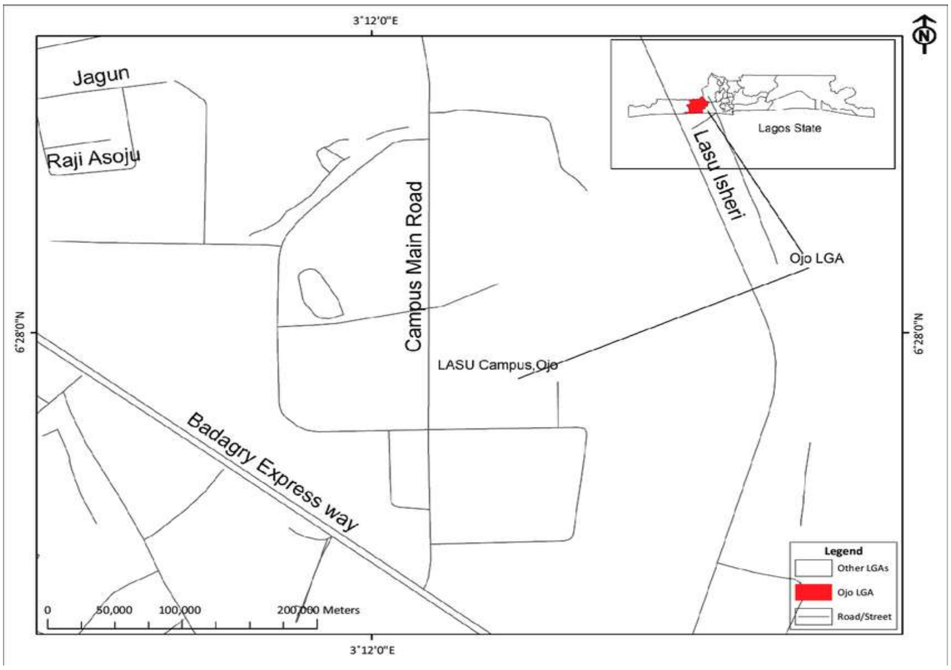

Fig 1: *Map of Ojo Local Government showing Alaba research area*

Study Area

Lagos State, located in the southwestern part of Nigeria, is characterized by a unique geological setting that plays a significant role in its environmental and infrastructural development. The area lies on the geographic coordinates of latitude 6.4500° N and longitude 3.2000° E. The state's geology is primarily shaped by its coastal location along the Gulf of Guinea, with a landscape dominated by sedimentary formations, coastal plains, lagoons, and creeks. Ojo Alaba which is the study area is situated near the Lagos lagoon, by the Badagry Expressway, around 20 kilometers from the Lagos city center. It spans a few neighborhoods like Alaba Rago, Alaba Onilu, Alaba Isale Oko, and Alaba Suru in Ojo. The area has a tropical wet climate, very hot and humid most of the year with two rainy seasons. Due to its proximity to the lagoon, it experiences moderate to high rainfall. It is low-lying and susceptible to flooding during the peak rainy season because of poor drainage infrastructure. Ojo Alaba is best known as the hub of international trade and technological markets in Nigeria. The International Trade Fair complex located here hosts major consumer goods trade fairs annually that attract traders from within and outside Nigeria. The Alaba International Market is the largest electronics market in Africa. All kinds of electronics, from household appliances, mobile phones, televisions, generators, audio devices, to spare parts are traded here. Most goods are sourced from Asia and sold at wholesale and retail prices to traders who supply across West Africa. Thousands of local and foreign traders operate in this market generating huge revenues. Associated markets like Alaba Suru market have also emerged around Alaba International market.

Materials and Methods

Materials

The materials used were: e-waste contaminated soil sample, rice husk ash, portland cement and water.

E-waste Soil Sample: The e-waste contaminated soil sample labeled AL1 was collected from an existing electrical and electronic dump site at Jagun area at Alaba International market, Ojo, Lagos State, Nigeria, at a depth not less than 1m below the ground level using the disturbed sampling technique. The soil description, sampling depth and date of sampling was done in the field before the e-waste contaminated soil sample was brought to the laboratory. The e-waste contaminated soil sample was air-dried for two weeks to allow for partial elimination of natural water content which may influence the analysis, then sieved with sieve No. 4 (4.75mm opening) to remove large particles and debris in order to get the final soil sample for the tests. After the drying period of two weeks, lumps in the sample were pulverized, using a pestle and mortar under minimal pressure.

Rice Husk Ash (RHA): The rice husk fibre was obtained from a rice milling factory in Agbara area of Lagos state, Nigeria. The rice husk fibre was burnt in open atmosphere: and the black ashes obtained were heated in a muffle furnace for 2 hours at 650 °C to 750 °C to obtain a white coloured ash by the rice mill. The burning process were carried out to enable the transformation of the silica content into amorphous phase which can react with the Calcium hydroxide CaOH liberated during the hardening of cement to further form cementitious compounds.

Portland cement: This was obtained from an open market in Magodo Area of Lagos State, Nigeria.

Water: The water used was obtained from the running taps in the laboratory; the source was borehole. Distilled water was not used so as to obtain results that would reflect in-situ conditions.

Methods

The e-waste contaminated soil sample which has passed through the 4.75mm sieve was also subjected to compaction tests and the California bearing ratio (CBR) in its natural state. The e-waste contaminated soil sample (designated as AL1) was stabilized using varying percentages of portland cement and RHA. The stabilization process was carried out in a matrix format, where cement content was varied at **0**%, 2%, 4%, 6%, 8%, and 10% by dry weight of soil, and for each cement level, RHA was added at 0%, 2%, 4%, 6%, 8%, and 10% by dry weight of soil.

This resulted in a total of 36 mix combinations, including control samples. The control sample had 0% cement and 0% RHA. Each mix was labeled based on its respective cement and RHA content. For example, a mix with 2% cement and 4% RHA was prepared by replacing 2% of the soil weight with cement and 4% with RHA, keeping the total soil mass constant.

The mix proportions were determined on a dry weight basis, and the soil, cement, and RHA were thoroughly mixed to ensure uniform distribution. Water was then added to achieve the OMC determined through standard Proctor compaction tests. The samples were compacted in molds to obtain MDD, and subsequent geotechnical and strength tests were conducted.

The modified method of the CBR was followed in conformity with the recommendation of the Nigerian General Specification, which stipulates that specimens be cured for six days unsoaked, immersed in water for 24 hours and allowed to drain for 15 minutes before testing. The UCS test was conducted in accordance with to evaluate the strength characteristics of the untreated and cement-treated e-waste contaminated soil samples. The UCS test is a quick and effective means of assessing the shear strength of cohesive soils without lateral confinement. The entire tests were carried out according to BS 1377 for natural soil sample and British Standard 1924 for stabilized samples.

Results and Discussion

Geotechnical characteristics of the natural soil

Table 1: Engineering Properties of AL1 e-waste soil before treatment

PROPERTIES	E-WASTE SOIL SAMPLES (CONTROL) AL1
Maximum Dry Density (g/cm^3)	
Optimum	1.73
Optimum Moisture Content (%)	16.75
California Bearing Ratio (%)	10.78
Unconfined compressive strength (kPa)	127.45
Cohesion (kPa)	20
Angle of internal friction Θ^0	24
Consistency Limit (%)	
Liquid Limit	44.45
Plastic Limit	19.09
Plasticity Index	25.36
Soil Classification	A-2-6
Colour	Light Brown
Soil Type	Silty-Clayey Sand

Table 1 shows the properties of the AL1 e-waste soil sample (control) and it highlights several key characteristics of silty-clayey sand, a soil type typically found in areas with a mix of fine and coarse particles. The MDD is 1.73 g/cm³ with an OMC of 16.75%, indicating the soil has a relatively moderate density and moisture content. This suggests a balance between compaction and water content, typical of silty-clayey soils that require a higher moisture

content to achieve maximum compaction (Yoo & Lee, 2008). California Bearing Ratio (CBR) of 10.78% is relatively low, implying that the soil has poor load-bearing capacity in its natural state, which can be attributed to the presence of fines (clay and silt) that reduce the soil's strength under load (Sherwood, 1993). Unconfined Compressive Strength (UCS) of 127.45 kPa is typical of silty-clayey soils, which generally have moderate strength. The presence of both fine particles and moisture retention contributes to this relatively low compressive strength (Amadi, 2010). The soil exhibits 20 kPa cohesion and an angle of internal friction (ϴ) of 24°, suggesting a reasonable shear strength. The combination of cohesion and friction is characteristic of clayey soils that rely on particle interlocking and cohesion for stability (Das & Sobhan, 2013). Classified as A-2-6 under the AASHTO system, this indicates the soil is a silty or clayey sand with fair to poor engineering properties (Amadi, 2010). The light brown color further suggests the presence of organic content and the fine-grained nature of the material.

Geotechnical properties of the stabilized soil

Table 2: Summary of all test result for e-waste soil samples AL1 treated with cement

E-waste Soil sample	Cement content	Max. Dry Density (MDD) (g/cm^3)	Optimum Moisture Content (OMC) %	CBR Unsoaked **(%)**	Triaxial Test Deviatior Stress **σ^3 (KN/m^2)**	Triaxial Test Cohension **(KN/m^2)**	Angle of Friction **$(\Theta)^0$**	UCS **Uncured** (kPa)
	0%	1.73	16.75	10.78	294.89	20	24	127.45
	2%	1.80	16.70	20.42	342.75	16	25	136.34
	4%	1.90	16.20	27.96	408.06	14	25	176.65
AL1	6%	2.10	16.15	30.09	552.56	09	27	210.05
	8%	1.95	15.87	29.95	533.75	12	19	186.80
	10%	1.82	15.39	28.05	515.20	14	18	186.05

Table 2 shows results of the impact of cement stabilization on e-waste soil and its suitability for construction purposes. The **MDD** increased from **1.73 g/cm^3** for the untreated soil to **2.10 g/cm^3** at 6% cement content. The increase in MDD can be attributed to the cement particles filling the voids in the soil, resulting in better compaction and increased dry density. This trend is consistent with findings by **Amadi (2010)**, who noted that cement stabilization improves soil compaction by reducing the void ratio and enhancing particle interlocking. However, beyond 6% cement content, the MDD decreases, likely due to the formation of **cementitious products** that may cause flocculation of particles and reduce the compaction efficiency (Olufowobi *et al.*, 2014). The **OMC** decreases slightly with increasing cement content, from **16.75%** for the untreated soil to **15.39%** at 10% cement. This reduction is expected, as cement absorbs some of the moisture during hydration, reducing the water required for compaction (Amadi, 2010). The cement particles also act as a binding agent, reducing the soil's water retention capacity. The **CBR** values increased significantly with cement stabilization, from **10.78%** for the untreated soil to **30.09%** at 6% cement content. This improvement in CBR is due to the **pozzolanic reactions** between the cement and soil, forming **calcium silicate hydrate (C-S-H)**, which improves the soil's strength and load-bearing capacity. Beyond 6% cement, the CBR decreases slightly, possibly due to the excessive amount of cement disrupting the optimal particle arrangement in the soil, as noted by **Muntohar (2011)**. The **deviator stress (σ3)** and **cohesion (c)** values show a general increase with cement content up to 6%, reflecting improved strength characteristics due to the formation of **cementitious bonds** that enhance particle bonding. The **deviator stress** increased from **294.89 KN/m^2** at 0% cement to

552.56 KN/m² at 6%, while **cohesion** decreased from **20 KN/m²** at 0% to **9 KN/m²** at 6%. The reduction in cohesion with higher cement content may be due to cement particles reducing the plasticity and ductility of the soil, which decreases its capacity to hold together under stress. The **angle of friction (Ө)** shows an initial increase from **24°** at 0% to **27°** at 6% cement, suggesting an enhancement in shear strength due to improved interparticle friction from cement stabilization. However, the angle of friction decreases beyond 6%, which may be due to excessive cement disrupting the natural soil matrix (Akinmusuru & Akinola, 1999). The **UCS** values show a steady increase with cement content, from **127.45 kPa** for the untreated soil to **210.05 kPa** at 6% cement. This increase is due to the **hydration reaction of cement**, which forms **calcium hydroxide** and **C-S-H**, enhancing the soil's strength. Beyond 6% cement, the UCS remains relatively stable, suggesting that further addition of cement may not significantly improve the strength beyond a certain threshold (Sharma & Lewis, 1994).

Geotechnical properties of RHA-Cement stabilised soil

Table 3: Summary of all test result for e-waste soil samples AL1 treated with cement and RHA

E-waste Soil sample	cement	Rice husk ash (RHA)	Max. Dry Density (MDD) (g/cm^3)	Optimum Moisture Content (OMC) (%)	CBR Unsoaked **(%)**	Deviatior Stress σ^3 **(KN/m^2)**	Triaxial Test Cohension **(KN/m^2)**	Angle of Friction **$(\Theta)^0$**	UCS **Uncured (kPa)**
		0%	1.73	16.75	10.78	583.50	20	24	127.45
		2%	1.75	17.01	14.56	587.40	16	26	132.34
	0%	4%	1.87	17.45	15.60	595.45	14	26	135.44
		6%	2.10	17.60	29.05	625.05	10	28	154.20
		8%	2.05	17.85	22.05	550.30	15	24	129.67
		10%	1.97	18.23	19.45	508.45	13	23	121.34
		0%	1.80	16.70	20.42	342.75	16	25	136.34
		2%	1.87	16.80	27.45	365.75	14	28	127.52
		4%	1.92	16.90	32.05	405.20	11	27	145.05
	2%	6%	2.20	17.25	39.50	485.20	09	29	168.85
		8%	2.12	17.65	33.89	338.45	15	26	152.48
		10%	1.98	17.75	32.54	312.40	14	25	140.85
		0%	1.90	16.20	27.96	408.06	14	25	176.65
		2%	2.18	16.60	31.45	425.62	12	26	186.84
		4%	2.28	16.75	48.25	515.50	11	27	191.95
	4%	6%	2.89	17.05	60.45	583.50	09	29	198.48
AL1		8%	2.15	17.21	50.56	567.40	15	26	182.48
		10%	2.00	17.85	42.60	525.45	10	24	180.65
		0%	2.10	16.15	30.09	552.56	09	27	210.05
		2%	2.15	16.25	30.56	547.40	13	26	211.65
	6%	4%	2.22	16.45	40.60	575.45	15	26	221.95
		6%	2.75	16.70	59.05	615.05	07	28	276.84
		8%	2.05	16.85	42.05	540.30	16	24	256.05
		10%	1.98	17.15	35.45	518.45	13	22	231.92
		0%	1.95	15.87	29.95	533.75	12	19	186.80
		2%	2.05	15.90	37.45	544.75	14	20	187.52
	8%	4%	2.13	16.20	42.05	575.20	18	22	194.05
		6%	2.64	16.35	49.50	595.20	11	26	218.85
		8%	2.30	16.40	33.89	538.45	15	24	182.48
		10%	2.13	16.45	32.54	532.40	14	22	180.85
		0%	1.82	15.39	28.05	515.20	14	18	186.05
		2%	1.87	15.60	31.45	525.62	16	22	196.84
	10%	4%	1.97	15.75	38.25	535.50	19	24	198.95
		6%	2.13	16.05	40.45	583.50	11	28	232.48
		8%	2.04	16.21	30.56	567.40	15	24	211.48
		10%	1.94	16.85	22.60	555.45	13	21	190.65

Table 3 provides results for e-waste soil (AL1) treated with various combinations of cement and rice husk ash (RHA), to evaluate its geotechnical properties. **Maximum Dry Density (MDD)** shows a general increase with increasing cement and RHA content. At 6% cement and RHA, the MDD reaches a peak of **2.75 g/cm³**, indicating that a combination of cement and RHA improves the compaction properties of the soil. The increase in density is due to the **pozzolanic reaction** between the cement, RHA, and soil, which forms cementitious products like **calcium silicate hydrates (C-S-H)** and **calcium aluminate hydrates (C-A-H)** that fill voids and bind soil particles together (Amadi, 2010). The high RHA content may also contribute to a better particle arrangement, reducing voids in the soil matrix (Muntohar, 2011). However, at higher RHA content (10%), the MDD shows a slight reduction, suggesting that excessive RHA content might cause flocculation and reduce the efficiency of compaction. This is consistent with findings by **Olufowobi *et al.* (2014)**, where excessive stabilizing agents reduced the soil's density. **Optimum Moisture Content (OMC)** increases slightly as the RHA content rises, particularly at higher percentages (up to 18.23% OMC at 10% RHA and 0% cement). This trend is expected because RHA, being a pozzolanic material, has a high surface area and tends to absorb more water.

Cement also absorbs water during hydration, but the combination of cement and RHA stabilizes the soil matrix, reducing the total water required for maximum compaction at lower RHA contents (Muntohar, 2011). **California Bearing Ratio (CBR)** values increase with cement and RHA content, peaking at **60.45%** for the combination of 6% cement and 6% RHA. This improvement is due to the development of cementitious compounds that enhance soil strength, making it more resistant to deformation under load. Beyond this point, the CBR values decrease slightly with higher cement and RHA content (as seen at 10%), possibly due to the reduced ability of the soil to compact efficiently under excess stabilizer (Benson & Trast, 1995). **Deviator Stress (σ3)** increases as the cement and RHA content increases, indicating an enhancement in the shear strength of the soil. At **6% cement and 6% RHA**, the deviator stress reaches **615.05 KN/m²**, demonstrating the beneficial effect of stabilization. The presence of cementitious products formed by the reaction of RHA with cement enhances particle interlocking and resistance to shearing (Sharma & Lewis, 1994). However, at higher RHA content (8% and above), the deviator stress tends to decrease, possibly due to the formation of brittle, less flexible compounds that reduce the ability of the soil to accommodate stress. **Cohesion (c)** shows a general decrease with increasing cement content but stabilizes with the addition of RHA. At 6% cement and 6% RHA, the cohesion is at its lowest (**7 KN/m²**). This reduction can be explained by the stiffening of the soil matrix as the cement and RHA react, which reduces plasticity and the soil's ability to hold together.

RHA, when mixed with cement, reduces the plasticity index of soils, contributing to this behavior (Olufowobi *et al.*, 2014). **Angle of Friction (Ɵ)** increases with cement and RHA content, reaching a maximum of **29°** at **6% cement and 6% RHA**. This suggests improved interparticle friction due to the cementitious compounds forming bonds between soil particles, which increase the soil's shear strength (Akinmusuru & Akinola, 1999). Beyond 6% RHA, the angle of friction slightly decreases, possibly due to the disruption of the natural soil structure by excessive stabilizer content. **Unconfined Compressive Strength (UCS)** values show a marked improvement with increasing cement and RHA content, reaching **276.84 kPa** at **6% cement and 6% RHA**. This indicates that the combination of cement and RHA significantly improves the compressive strength of the soil, mainly due to the formation of durable **C-S-H** and **C-A-H** gels that strengthen the soil structure (Sharma & Lewis, 1994). Beyond 6% RHA, the UCS values decrease slightly, likely due to over-stabilization, which results in the formation of brittle compounds that limit the soil's compressive strength.

Environmental Impact

The stabilization improves the mechanical properties of the soil, making it more suitable for construction and reducing the need for excavation and disposal of contaminated soils, which can lead to further environmental degradation (Alhassan *et al*., 2020). Treating e-waste contaminated soils with cement and RHA can immobilize heavy metals and other toxic substances present in the e-waste. This process reduces the leachability of contaminants, minimizing the risk of groundwater and soil pollution (Sharma & Awasthi, 2021). RHA is a byproduct of rice milling, which is often disposed of as waste. Using RHA in soil stabilization promotes sustainable waste management practices by recycling agricultural residues, thus reducing waste and its associated environmental impacts (Omar *et al*., 2020). The production of cement is energy-intensive and contributes significantly to CO2 emissions. By incorporating RHA into cement-based treatments, the overall carbon footprint can be reduced, as RHA can partially replace cement, lowering the amount of cement needed for stabilization (Khan *et al*., 2020).

Conclusion

The control sample AL1, being a silty-clayey sand with moderate compaction and strength properties, would require stabilization to enhance its performance for engineering applications. The baseline CBR, UCS, and shear strength values indicate that the soil in its natural state might not meet the requirements for construction projects that demand higher load-bearing capacities and durability. Therefore, treatment with stabilizing agents such as cement and rice husk ash would be necessary to improve its engineering properties and make it suitable for use in infrastructure development. Stabilizing the e-waste soil sample AL1 with cement improves its engineering properties, particularly its MDD, CBR, deviator stress, and UCS. The optimal cement content appears to be around 6%, where the soil achieves the highest values in terms of compaction, load-bearing capacity, shear strength, and compressive strength which makes them suitable for supporting infrastructure without the need for costly excavation and replacement. Beyond 6% cement, there is a slight decline in these properties, indicating that over-stabilization might negatively impact the soil's performance. Therefore, at 6% cement content is recommended for achieving the best balance of strength and durability for this specific e-waste contaminated soil sample. The stabilization of the e-waste soil sample AL1 with a combination of cement and RHA significantly improves its engineering properties. These improvements indicate that the stabilized soil is more suitable for road and embankments construction, with enhanced load-bearing capacity, shear strength, and compressive strength. However, further increases in stabilizer content beyond 6% tend to reduce these properties, suggesting that there is an optimal range for the effective use of cement and RHA in soil stabilization. The increased cohesion and angle of internal friction in treated soils provide better stability and resistance to erosion, making them suitable for supporting embankments that are subject to dynamic loads and environmental conditions, increase in the California Bearing Ratio (CBR) of the soil, which is crucial for road performance. A higher CBR value indicates better load distribution and resistance to deformation under traffic loads, leading to durable road structures.

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