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# COMPACTION AND STRENGTH CHARACTERISTICS OF CEMENT STABILIZED LATERITIC SOIL ADMIXED WITH CRUMBED ELECTRONIC WASTE FOR ROAD CONSTRUCTION

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**Abstract**
Road pavement is built on lateritic soil as foundation or subgrade course of the road but it's often characterizes with low strength, and poor durability. Cement and lime have been found to be effective as conventional stabilizers for lateritic soil; however, their productions have been attributed to the high carbon emissions. At the same time, the mismanagement and unsafe recycling of electronic waste pose a major environmental threat in Nigeria, even though the sector holds considerable economic value. This study therefore assesses the stabilizing effect of crumbed e-waste and cement on lateritic soil to create a sustainable, high-performance road pavement material. Laboratory tests were conducted on soil samples treated with varying e-waste (0–9%) and cement (0–15%) contents. The soil was characterized for particle size, Atterberg limits, and compaction, while stabilized samples were tested for CBR. The natural soil was clayey with moderate plasticity, and poor bearing capacity (CBR < 5%). The presence of e-waste content (6%) enhanced interparticle friction and stiffness while cement improved the bonding properties within the matrix of mixture of lateritic soil and e-waste thereby enhancing its strength. The required strength performance of the mixture was achieved with 10% cement and 6% e-waste for sustainable approach to lateritic soil stabilization.

***Keywords***
*Cement, E-waste, Environmental sustainability, Lateritic soil, Soil stabilization, Strength*

## 1. INTRODUCTION

Soil stabilization is an important procedure which involves the careful combination and mixing of various additives to improve soil properties as applicable to civil engineering [1]. The main goal is to improve the load-bearing capacity of soil, such that it can withstand imposing loads and pressures. It also aims to improve soil resistance to volume changes, prevent undesirable shifts or deformations. Additionally, it helps improving the dry unit weight of the soil to meet various geotechnical purposes [2]. This is particularly applicable to lateritic soil as foundation material for infrastructural construction.

Lateritic soils are a unique and widely distributed type of soil predominantly found in tropical and subtropical regions of the world [3]. These soils undergo an intense weathering process known as laterization, which results in the leaching of silica and the accumulation of iron and aluminum oxides [4]. As a result, lateritic soils play a significant role in construction activities, particularly in road infrastructure, where they are commonly used for subgrade and pavement layers [5]. Additionally, their adaptability makes them a valuable material for the construction of reinforced embankments. However, despite their widespread availability and potential, lateritic soils often exhibit undesirable engineering properties such as low bearing capacity, high permeability, and excessive shrink-swell behavior when subjected to moisture fluctuations. These limitations can compromise the structural integrity of roadways and embankments, leading to premature failure. To enhance their performance, stabilization techniques are frequently employed to improve their strength, durability, and overall engineering properties, ensuring their suitability for long-term infrastructure development [6].

Conventional stabilizers, such as cement and lime, are widely used in soil stabilization to enhance the strength and durability of weak soils. These materials contributed to environmental pollution due to their energy-intensive production processes, which release substantial amounts of Carbon dioxide ($CO_2$) into the atmosphere. Cement production alone accounts for approximately 8% of global $CO_2$ emissions, making its extensive use a pressing environmental concern [7], [8]. Similarly, lime production involves high-temperature calcination processes that result in significant greenhouse gas emissions. The environmental impact of these stabilizers has led researchers to explore alternative, eco-friendly stabilizer that can mitigate carbon footprints while ensuring sustainable construction practices [9], [10]. However, they remain the major stabilizers due to their ability to impact strength development by bonding soil particles together or reducing plasticity of the soil to make it more workable through cation exchange process between the clay minerals and the stabilizers [11], [12].

In Nigeria, improper disposal of electronics wastes (E-wastes) which emanates from rapid demand for electronic products such as mobile phones, computers, solar panels, electric vehicles, and laptops to boost economic growth, and the need for both public and private enterprises to frequently replace outdated electronics, has become a growing environmental and public health concern. The country generates approximately 1.1 million metric tons of e-waste annually, ranking among the highest producers in Africa [13]. E-waste, which includes non-biodegradable components such as plastics, circuit boards, and glass fibres, poses a significant environmental hazard if not properly managed [14]. Major cities like Lagos, Abuja, and Port Harcourt serve as hubs for both domestic and imported e-waste, much of which is discarded without proper treatment or recycling. Informal recycling practices, such as open burning and acid leaching of electronic components, release hazardous substances like lead, mercury, cadmium, and brominated flame retardants, contaminating soil, polluting water sources, and emitting toxic fumes into the atmosphere [15]. The development of stabilization techniques in which materials like e-waste is admixed with traditional stabilizers may not only addresseses the problem of waste disposal and management at large, but also offers a practical and environmentally friendly solution for improving engineering performance of soil as subgrade material and at the same time promoting circular economy principles [16]. Recent studies [17], [18], [19], [20] have explored various sustainable materials for soil stabilization, with differing levels of effectiveness and environmental impact. Almuaythir et al. [21] investigated the use of industrial waste materials to stabilize expansive clay soils and reported improved strength and reduced plasticity due to cementitious compound formation. In another study, Nyagah [22] examined the use of Foundry Clay Dust (FCD) and Cement Dust Ash (CDA) for soil stabilization, concluding that FCD was effective at 6% replacement while CDA's performance declined above 6%. Similarly, Kiran-Kumar and Praveen-Kumar [23] evaluated soil stabilization using powdered e-waste, finding notable enhancements in shear strength and slope stability. Several other works explored agricultural and industrial waste applications. Marczuk et al. [24] assessed manure spreader parameters, finding reduced soil compaction and better productivity with larger spreaders, but their work had no direct relevance to soil stabilization. Etim et al. [25] combined lime and Periwinkle Shell Ash (PSA) for pavement layer stabilization, achieving maximum strength with 8% lime and 8% PSA, although rice husk ash (RHA) and e-waste additives were not considered. Iyaruk et al. [5] reported that biomass ash stabilized with 5% cement met pavement standards, suggesting its potential as a partial cement replacement, though e-waste approaches were not tested. Teerawattanasuk and Voottipruex [26] also highlighted the advantages of geopolymer stabilization using fly ash and cement, which produced faster strength gains than conventional cement stabilization, but they did not include RHA or e-waste. Collectively, previous studies have demonstrated considerable progress in sustainable soil stabilization using industrial and agricultural wastes. However, there remains a clear research gap in the integration of E-wastes as a partial stabilizing agent with cement or other binders. Addressing these issues requires sustainable waste management strategies that encourage recycling, circular economy practices, and the reuse of e-waste materials in construction applications. Repurposing crumbed e-waste in soil stabilization offers dual benefits—reducing environmental pollution and improving soil performance for infrastructure development [27]. Previous studies, such as those by Obianyo et al. [28] and Kiran-Kumar and Praveen-Kumar [23], have shown that incorporating E-wastes into soil can enhance California Bearing Ratio (CBR) and other strength parameters. However, there remains limited exploration of crumbed e-waste as a sustainable stabilizing material. This study, therefore, seeks to bridge these gaps by investigating the stabilization of lateritic soil using cement admixed with crumbed e-waste. The research aims to enhance the geotechnical properties of the lateritic soil as foundation material, thereby addressing both soil instability and e-waste management challenges in a sustainable manner.

## 2. MATERIALS AND METHOD

### 2.1 Study Area

Lateritic soil samples were obtained from a borrow pit along the University of Ilorin permanent site access road, Ilorin East Local Government Area, Kwara State, Nigeria. The site lies at latitude 8.479°N and longitude 4.541°E within the humid tropical climatic zone. Samples were sealed in moisture-proof bags and transported to the Geotechnical Laboratory at University of Ilorin, where the initial moisture content was determined by oven-drying in accordance with BS 1377: Part 2 [29].

### 2.2 Materials

The materials used for this study included lateritic soil, processed e-waste, Portland Limestone Cement (PLC), and potable water. The lateritic soil samples, collected from a borrow pit in Ilorin, Kwara State, were air-dried, pulverized, and sieved through a 4.75 mm BS sieve after determination of their natural moisture content. The e-waste materials were sourced from electronic repair shops in Tanke, Ilorin, and consisted primarily of discarded printed circuit boards (PCBs), cables, and minor plastic and metallic components. The collected e-waste was cleaned, dried, mechanically shredded, and subsequently ground into a fine powder passing through a 75 µm BS sieve. This uniform particle size was adopted to enhance homogeneity and improve interaction with the soil matrix during stabilization. The PLC used in this study was obtained from Mohadis Construction Limited, Ilorin, and conformed to BS EN 196-3 [30] specifications. Clean potable water was used for all mixing and compaction processes.

**Dump site of E waste** **Shredding** **E-Wastes after grading**

**Figure 1: Production process of E-wastes**

## 2.3 Preliminary Tests on Materials

Comprehensive preliminary tests were carried out on the cement, lateritic soil, and crumbed e-waste to determine their physical and chemical properties prior to stabilization. All tests were conducted at the Civil Engineering Laboratory, Faculty of Engineering, University of Ilorin, Kwara State, Nigeria, following BS 1377:1990 standards.

### *2.3.1 Lateritic soil*

The reddish-brown lateritic soil, commonly used in construction, is rich in iron and aluminum oxides, exhibiting a clayey to sandy texture depending on depth and degree of weathering. The oxide composition of the laterite was determined using X-Ray Fluorescence (XRF). In addition, several geotechnical tests were carried out to evaluate its properties, including specific gravity, particle size distribution, Atterberg limits, compaction, and strength characteristics. The specific gravity was determined using the pycnometer method in accordance with BS 1377-2 [29], providing insight into the soil's density and mineralogical composition. Particle size distribution was analyzed through standard sieve analysis following BS 1377-2:1996, using a 500 g representative sample washed on a 75 µm sieve, oven-dried at 110 °C for 24 hours, and subsequently classified using AASHTO and USCS systems to assess grading characteristics. The Atterberg limits—Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI)—were determined using the Casagrande apparatus and rolling thread method in accordance with BS 1377-2:1996, to evaluate the soil's consistency and its susceptibility to volumetric changes with moisture variation. The compaction characteristics were established using the British Standard Light (BSL) compaction test in accordance with BS 1377-4:1990, employing a 2.5 kg rammer dropped from a height of 300 mm in three layers with 27 blows per layer, to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC).

### *2.3.2 E-wastes*

The processed e-waste used in this study consisted mainly of printed circuit boards (PCBs) with minor plastic and metallic inclusions. The materials were thoroughly cleaned to remove contaminants, oven-dried, and mechanically ground into fine powder passing through a 75 µm BS sieve. This particle size was selected to ensure uniform dispersion within the soil matrix and to promote better interaction between the soil particles, cement, and e-waste during stabilization. The oxide composition of the processed e-waste was determined using X-Ray Fluorescence (XRF).

### *2.3.3 Mix proportions*

The required quantities of cement and crumbed e-waste shown in Table 1 were measured by weight of the lateritic soil and thoroughly mixed to ensure uniform distribution. The mix proportions were adapted relative to previous studies [23], [28] on the stabilization of lateritic soil with e-waste and cement. E-waste was incorporated at 0, 3, 6, and 9%, representing incremental additions of shredded electronic waste materials such as crushed PCBs, plastics, and metal components. Similarly, cement was introduced at 0, 5, 10, and 15% by weight of the soil to evaluate its individual and combined effects with e-waste on soil stabilization. The 0% e-waste with 0% cement, containing no electronic waste and cement served as the control mix was used as a baseline.

Table 1: Mix proportion

| E-Waste Replacement (%) ↓ Cement Replacement (%) → | 0% | 5% | 10% | 15% |
|---|---|---|---|---|
| 0% | 0, 0 | 5, 0 | 10, 0 | 15, 0 |
| 3% | 0, 3 | 5, 3 | 10, 3 | 15, 3 |
| 6% | 0, 6 | 5, 6 | 10, 6 | 15, 6 |
| 9% | 0, 9 | 5, 9 | 10, 9 | 15, 9 |

### *2.3.4 Compaction*

The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of lateritic soil stabilized with varying percentages of cement and e-waste were determined using the Standard Proctor method in accordance with BS 1377-4:1990. The test was conducted using a standard Proctor mould of 1000 cm³ volume. Different proportions of cement and e-waste were dry-mixed with the soil, followed by the addition of water. The mixtures were compacted in three layers, each receiving 27 blows from a 2.5 kg rammer dropped from a height of 300 mm. The moisture content and bulk density were determined for each mix, and dry density–moisture content relationships were established to obtain the OMC and MDD.

### *2.3.5 California bearing ratio*

The strength characteristics of the soil and stabilized mixtures were evaluated using the California Bearing Ratio (CBR) test in accordance with BS 1377-9:1990. For each mix, samples were compacted at their respective Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) as obtained from the Standard Proctor compaction test. The compacted specimens were prepared in standard CBR moulds (approximately 2250 cm³ volume), sealed, and soaked in water for 96 hours to simulate worst-case field conditions. Following soaking, penetration tests were conducted using a standard plunger at a constant rate of 1.25 mm/min. The loads corresponding to penetrations of 2.5 mm and 5.0 mm were recorded, and the CBR values were computed as ratios of measured loads to standard reference loads. The higher of the two values was reported as the CBR of the sample.

## 3. RESULTS AND DISCUSSION

### 3.1 Oxide compositions of lateritic soil and e-wastes

The XRF data in Table 2 show a laterite dominated by $SiO_2$ (40.82 wt.%), $Fe_2O_3$ (38.00 wt.%) and $Al_2O_3$ (14.86 wt.%), giving $SiO_2+Al_2O_3+Fe_2O_3 = 93.68$ wt.% and a silica-to-sesquioxide ratio $SiO_2/(Fe_2O_3+Al_2O_3) = 0.772$, which classifies the sample as a true (sesquioxide-rich) laterite or Fe rich laterite rather than a siliceous soil, and an $Al_2O_3/Fe_2O_3$ ratio ≈ 0.391 that indicates Fe-dominance over alumina typical of matured lateritic profiles (Waikhamnuan, *et al.*, 2025). This oxide balance - high $Fe_2O_3$ nearly equal to $SiO_2$ and substantial $Al_2O_3$ - is consistent with Santha-Kumar *et al.* [32] work that report laterites governed by the three major oxides $Fe_2O_3$, $SiO_2$ and $Al_2O_3$, although absolute Fe levels vary spatially (examples show $Fe_2O_3$ ranges from ~35–55 wt.% in tropical laterites). Practically, the high $Fe_2O_3+Al_2O_3+SiO_2$ content explains common laterite properties (red colour, sesquioxide nodules) and indicates possible use as roadfill or as a raw feed for cement/clinker after appropriate processing, but mineralogical (XRD), geotechnical and leachability checks are recommended before engineering or industrial application [33].

The analysis of the E-waste sample in Table 4 reveals that it is predominantly composed of silica ($SiO_2 = 56.11$ wt.%), calcium oxide ($CaO = 23.97$ wt.%), and magnesium oxide ($MgO = 20.52$ wt.%), indicating a highly siliceous and calcareous non-metallic fraction (glass-fibre/resin derived) with potential for pozzolanic and geopolymeric reactivity [34]. The moderate alumina ($Al_2O_3 = 7.34$ wt.%) and relatively high alkali oxides ($K_2O = 8.55$ wt.% and $Na_2O = 8.41$ wt.%) observed here are consistent with Nicoara et al. [35] work showing that waste electronic non-metallic fractions contain substantial aluminosilicate phases that can contribute to pozzolanic behaviour when appropriately processed.

### 3.2 Geotechnical characterization of materials

### *3.2.1 Particle size distribution*

The particle size distribution of the lateritic soil used is presented in Figure 2. Coarse particles (10–2.36 mm) were retained, indicating limited coarse content. The mid-size fraction (1.18–0.60 mm) formed the bulk of the sample, showing dominance of medium grains, while finer particles (< 0.425 mm) occurred in smaller amounts with a sharp fall at the 0.075 mm sieve. Overall, the soil exhibits a well-graded profile suitable for construction purposes such as road base and concrete work.

Table 2: Oxide compositions of lateritic soil and e-wastes

| **Components** | **Concentration (wt.%)** | |
|---|---|---|
| | Lateritic soil | E-waste |
| $SiO_2$ | 40.819 | 56.114 |
| $V_2O_5$ | 0.222 | 0.067 |
| $Cr_2O_3$ | 0.082 | 0.049 |
| $MnO$ | 0.195 | 0.249 |
| $Fe_2O_3$ | 38.001 | 5.269 |
| $Co_3O_4$ | 0.193 | 0.01 |
| $NiO$ | 0.095 | 0.241 |
| $CuO$ | 0.063 | 0.124 |
| $Nb_2O_3$ | 0.043 | 0.019 |
| $WO_3$ | - | 0.059 |
| $P_2O_5$ | 0.133 | 3.379 |
| $SO_3$ | 0.177 | - |
| $CaO$ | - | 23.971 |
| $MgO$ | 0 | 20.523 |
| $K_2O$ | 0.68 | 8.546 |
| $Al_2O_3$ | 14.855 | 7.339 |
| $Na_2O$ | 1.572 | 8.407 |
| $ZnO$ | 0.316 | 0.133 |
| $Ag_2O$ | 0.122 | 0.014 |
| $Cl$ | 0.429 | 0.246 |
| $ZrO_2$ | 0 | 0.116 |
| $SnO_2$ | 0 | 0 |

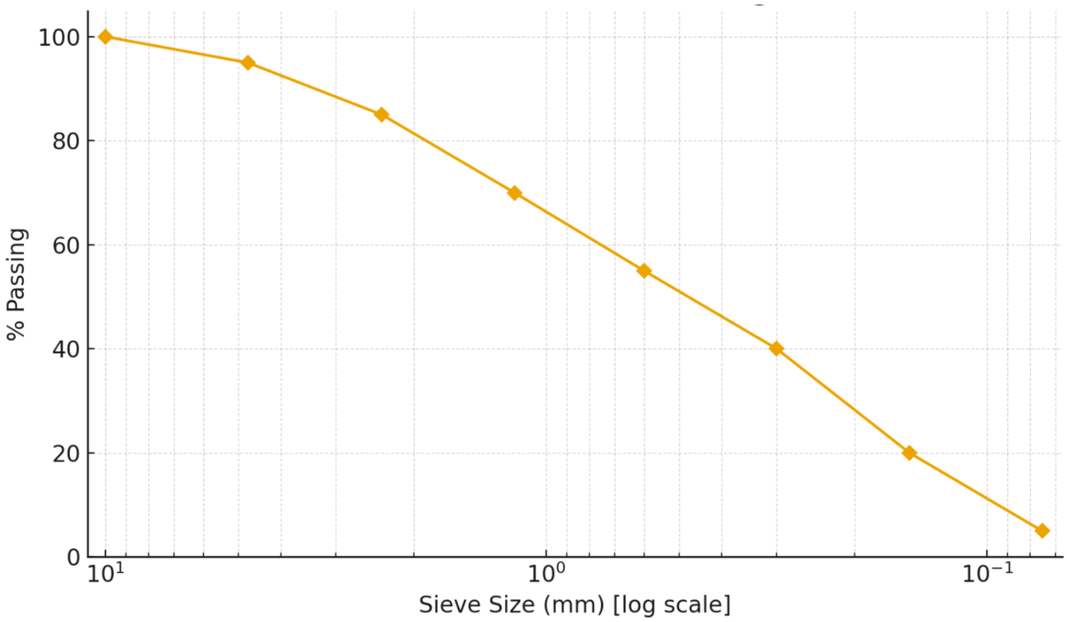

**Figure 2: Particle distribution of lateritic soil**

Table 3 shows that the soil has a Plastic Limit (PL) and Liquid Limit (LL) of 19.7% and 37.0%, respectively indicating the moisture content at which it transitions from semi-solid to a plastic state and from plastic to a liquid state normally characterized moderately plastic clayey laterites. The PI of 17.3% reflects a moderate plastic range. Overall, these results classify the soil as a medium-plasticity lateritic clay with good workability and stable behavior under controlled moisture conditions.

Table 2: Physical characteristics of lateritic soil

| Property | Value |
|---|---|
| Specific Gravity | 2.6 |
| Liquid Limit (LL), % | 37.00 |
| Plastic Limit (PL), % | 19.70 |
| Plasticity Index (PI), % | 17.30 |
| Flow Index (Fi), % | 17.00 |

### *3.2.2 Compaction results*

The results of MDD and OMC as compaction characteristics of the stabilized lateritic soil were presented in Figures 3 and 4, respectively. The baseline MDD was 1.64 g/cm³ with an OMC of 13.00%. Small additions of e-waste caused a slight increase in MDD, rising from the baseline value of 1.64 g/cm³ to approximately 1.68 g/cm³ at 6% e-waste, corresponding to an increase of about 2.4%, before declining at higher contents, with a concurrent gradual rise in OMC. Cement stabilization produced a marked densification effect, with MDD increasing to about 1.80 g/cm³ at 10% cement and a moderate rise in OMC. The blended mixes showed the best performance at 10% cement + 6% e-waste, achieving the highest MDD, while further additions led to reduced compaction efficiency due to increased porosity and water demand. These results further revealed that cement stabilization beyond 10% is not cost effective. These results are in conformity with report of Kiran-Kumar and Praveen-Kumar [23] and Iyaruk et al. [5].

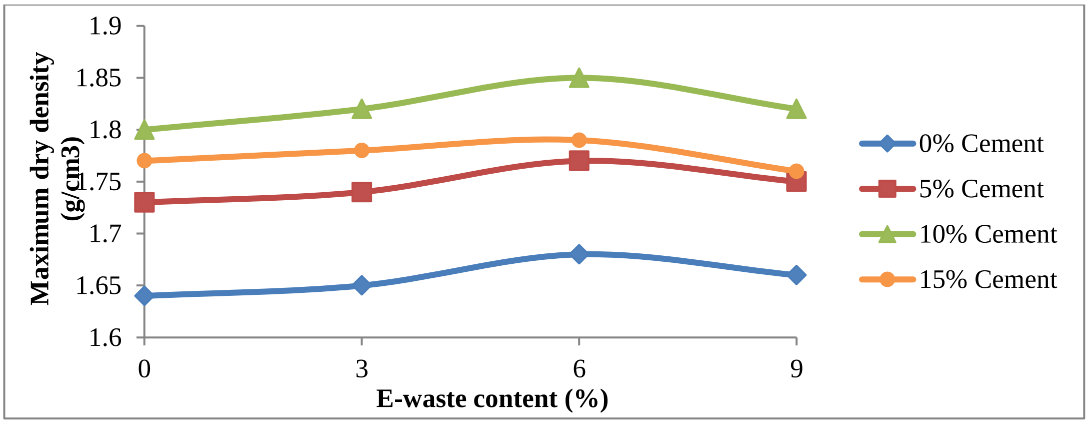

**Figure 3: Maximum Dry Density results**

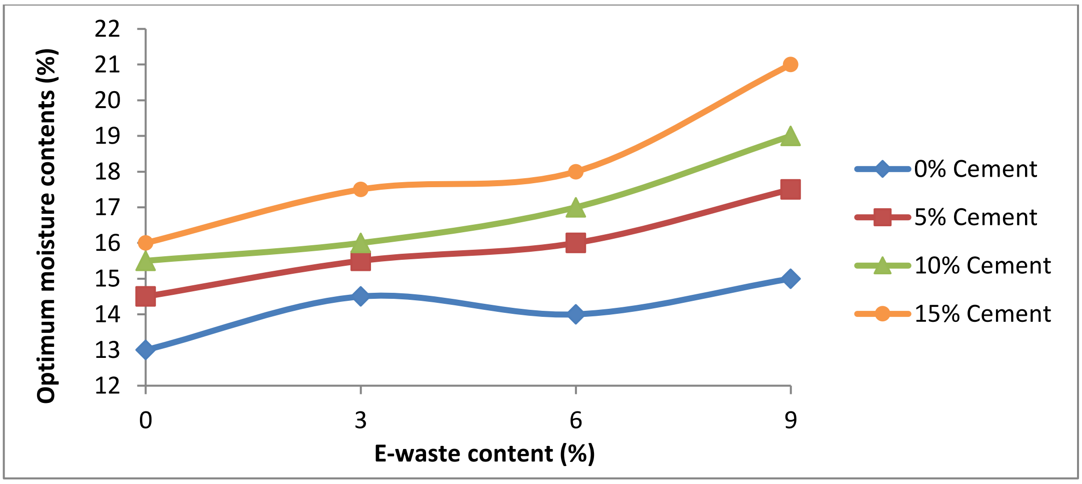

**Figure 4: Optimum Moisture content result**

### *3.2.3 California bearing ratio results*

The CBR results in Figures 5 and 6 reveal clear trends in the strength improvement of the soil when stabilized with cement, e-waste, and their combinations. The control sample recorded relatively low values, with 53% unsoaked and 22% soaked, indicating poor strength retention under moisture influence. The inclusion of only e-waste produced marginal improvements compared to the control, with peak values at 6% e-waste (59% unsoaked and 26% soaked), after which strength dropped slightly at higher dosage, suggesting the limited binding potential of e-waste on its own. This can be attributed to the inert and non-cementitious nature of crushed e-waste particles, which primarily act as micro-fillers rather than reactive binders. Their irregular shape may improve interlocking and reduce voids to some extent, but without sufficient pozzolanic or cementitious activity, the overall gain in strength remains minimal [36].

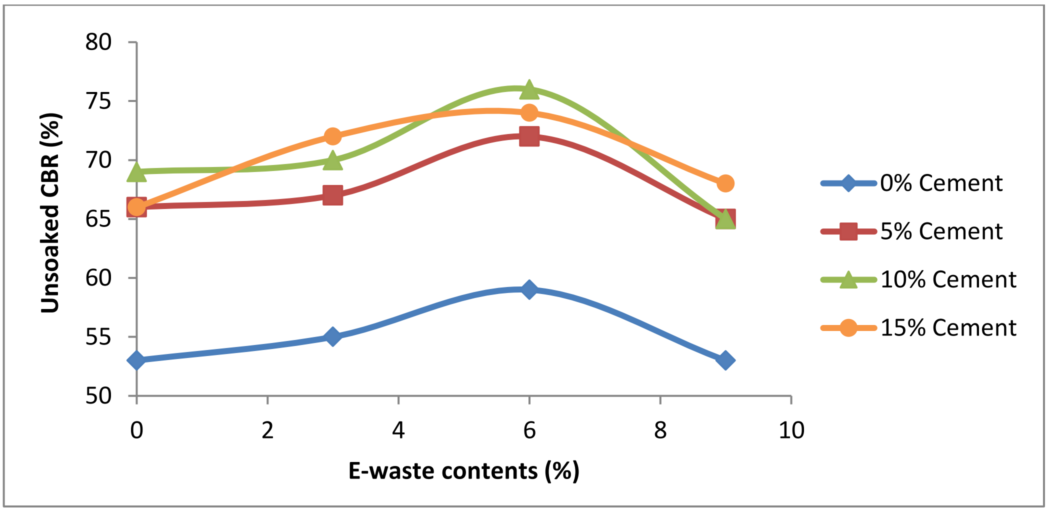

**Figure 5: Unsoaked CBR results**

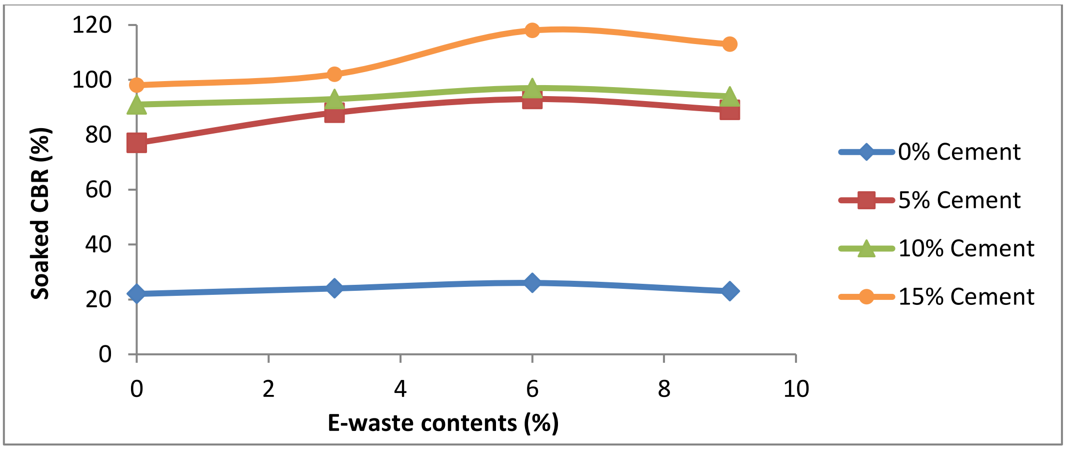

**Figure 6: Soaked CBR results**

In contrast, cement addition significantly enhanced CBR, with both soaked and unsoaked values showing substantial increases. For example, at 10% cement, the soaked CBR reached 91% while the unsoaked value was 69%, and at 15% cement the soaked CBR climbed as high as 98%, far exceeding the untreated soil. This strength improvement results from the hydration of cement forming calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H) gels, which fill pore spaces and bind soil particles into a dense matrix, thus improving load-bearing capacity and moisture resistance [37], [38]. The synergistic blends of cement and e-waste provided even better performance, with remarkable gains under soaked conditions where durability against water infiltration is critical. A blend such as 15% cement with 6% e-waste achieved the highest soaked CBR of 118%, while the unsoaked value also remained high at 74%. The enhanced performance can be explained by the micro-filler role of e-waste particles, which occupy voids within the cement-stabilized matrix, improving packing density and reducing permeability [39], [40]. Additionally, e-waste particles may act as nucleation sites for the precipitation of hydration products, promoting a more refined microstructure [41]. These findings align with previous study by Amadi et al. [42] reported that cement stabilization substantially increases CBR due to the formation of C–S–H bonds that improve soil cohesion and stiffness.

## 4. CONCLUSION

It is revealed from this study that:

i. The untreated lateritic soil classified as a well-graded, clayey soil with moderate plasticity, exhibited low bearing strength (soaked CBR <22%) with MDD of approximately 1.64 g/cm³ and OMC of 13%, consistent with fine-grained soils.

ii. Although crumbed e-waste, acting as a lightweight aggregate, reduced its dry density, but enhancing interparticle friction, particularly at moderate dosages (6–9%), the incorporation of cement significantly improved soil load bearing strength, with CBR increased up to 118% at 6% e-waste and 10% cement contents, respectively.

iii. A best mix of 10% cement with 6% crumbed e-waste was identified in term of its high traffic load bearing capacity. Although higher cement content (15%) offered marginal strength gains, increased costs and carbon footprint it embodied limit its use, thereby making 10% cement with moderate e-waste addition the most sustainable choice.

Based on the study findings, incorporating crumbed e-waste and cement in lateritic soil can significantly enhance strength. Mix containing 10% cement and 6% e-waste demonstrated the best strength and is therefore recommended for practical applications towards proper e-waste management and subgrade stabilization for low-cost road construction.

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