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Original Research Article

Mechanical, Durability and Microstructural Performance of Bio-Stabilized Compressed Earth Blocks Using *Parkia biglobosa* (Makuba)

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Abstract

The high environmental impact and cost of cement-based construction materials have intensified the search for sustainable alternatives. This study investigates the mechanical, durability, and microstructural performance of compressed stabilized earth blocks (CSEBs) incorporating *Parkia biglobosa* (Makuba) as a bio-based stabilizer. Lateritic soil was characterized using particle size distribution, Atterberg limits, and compaction tests, while Makuba extract was chemically analyzed. Blocks were produced with varying Makuba contents and cured for 7–28 days. Compressive strength, water absorption, and microstructural properties (SEM, EDX, XRD) were evaluated. Results show strength improvements of 25–60%, with peak values exceeding 3.0 N/mm², satisfying Nigerian Industrial Standard requirements. Water absorption decreased by 15–35%, remaining below 12%, while microstructural analysis revealed pore refinement, enhanced particle bonding, and matrix densification. The findings confirm Makuba as a viable low-cost, eco-friendly stabilizer capable of producing durable structural earth blocks suitable for sustainable housing applications.

Keywords: Compressed earth blocks; Bio-stabilization; Parkia biglobosa; Durability; Microstructure; Sustainable construction.

1. INTRODUCTION

The construction sector is responsible for a significant proportion of global carbon emissions, with cement production contributing approximately 8–10% of anthropogenic CO_2 emissions due to clinker manufacturing processes [1,2]. This environmental challenge, combined with rising construction costs, has intensified the demand for sustainable building materials, particularly in developing countries where housing deficits remain critical [3,4].

Compressed stabilized earth blocks (CSEBs) have emerged as a viable alternative due to their low embodied energy and reliance on locally available materials [5]. These blocks offer improved performance compared to traditional adobe; however, unstabilized earth materials suffer from low mechanical strength, high porosity, and susceptibility to water-induced degradation [6,7].

Stabilization techniques using cement and lime enhance performance through pozzolanic reactions that form calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H), resulting in improved matrix densification and strength [8,9]. Despite their effectiveness, these stabilizers are associated with high environmental impact and cost, limiting their sustainability [10].

Recent research has focused on bio-based stabilizers derived from agricultural waste materials, which provide environmentally friendly alternatives and improve soil properties through physicochemical interactions [11–13]. Materials such as rice husk ash, bagasse ash, and natural fibres have demonstrated improvements in compressive strength, durability, and resistance to environmental degradation [14–16].

Parkia biglobosa (Makuba), a widely available agricultural by-product in West Africa, has shown potential as a bio-stabilizer due to its high lignin, polysaccharide, and phenolic content [17]. These compounds facilitate stabilization through hydrogen bonding, clay flocculation, and pore refinement mechanisms [18,19].

However, while previous studies have focused on individual performance aspects, there is limited comprehensive evaluation of the combined mechanical, durability, and microstructural behaviour of Makuba-stabilized compressed earth blocks. This study therefore addresses this gap by integrating macro-scale performance evaluation with microstructural analysis.

2. MATERIALS AND METHODS

2.1 Materials

Lateritic soil used in this study was obtained from Kaduna State, Nigeria, and characterized in accordance with ASTM standards for particle size distribution, Atterberg limits, and classification [10]. The soil exhibited suitable properties for block production, including adequate fines content and plasticity required for compaction.

Makuba (*Parkia biglobosa*) pod extract was processed and used as a bio-stabilizer. The material contains lignins, pectins, and phenolic compounds, which contribute to stabilization through physicochemical interactions [8].

2.2 Mix Design and Specimen Preparation

Lateritic soil obtained from Kaduna State was characterized using standard procedures including particle size distribution, Atterberg limits, and classification in accordance with ASTM D2487 [20]. The soil exhibited suitable grading and plasticity for block production.

Makuba (*Parkia biglobosa*) extract was prepared and used as a stabilizer. Its chemical composition includes lignins, pectins, and phenolic compounds, which contribute to stabilization through bonding and pore refinement mechanisms [17].

Blocks were produced with varying stabilizer content and compacted using a manual compression system. Specimens were cured for 7, 14, and 28 days.

Testing Standards

- Compressive Strength: ASTM C39/C39M-21 [21]
- Water Absorption: ASTM C642-21 [22]
- Soil Classification: ASTM D2487-17 [20]
- Compactability: BS EN 12350-4:2019 [23]

Microstructural analysis was conducted using SEM, EDX, and XRD.

3. RESULTS AND DISCUSSION

3.1 Geotechnical Properties of Lateritic Soil

The lateritic soil exhibited characteristics typical of tropical residual soils, with a well-graded particle size distribution and moderate plasticity index. These properties are essential for achieving optimal compaction and inter-particle bonding, which directly influence the mechanical performance of compressed earth blocks [5]. The presence of fine particles enhances cohesion, while the sand fraction contributes to load-bearing capacity and dimensional stability. Figure 1 Table 1 shows Particle Size Distribution Curve of the Natural Soil Sample and the Properties of the Natural Soil Sample used respectively.

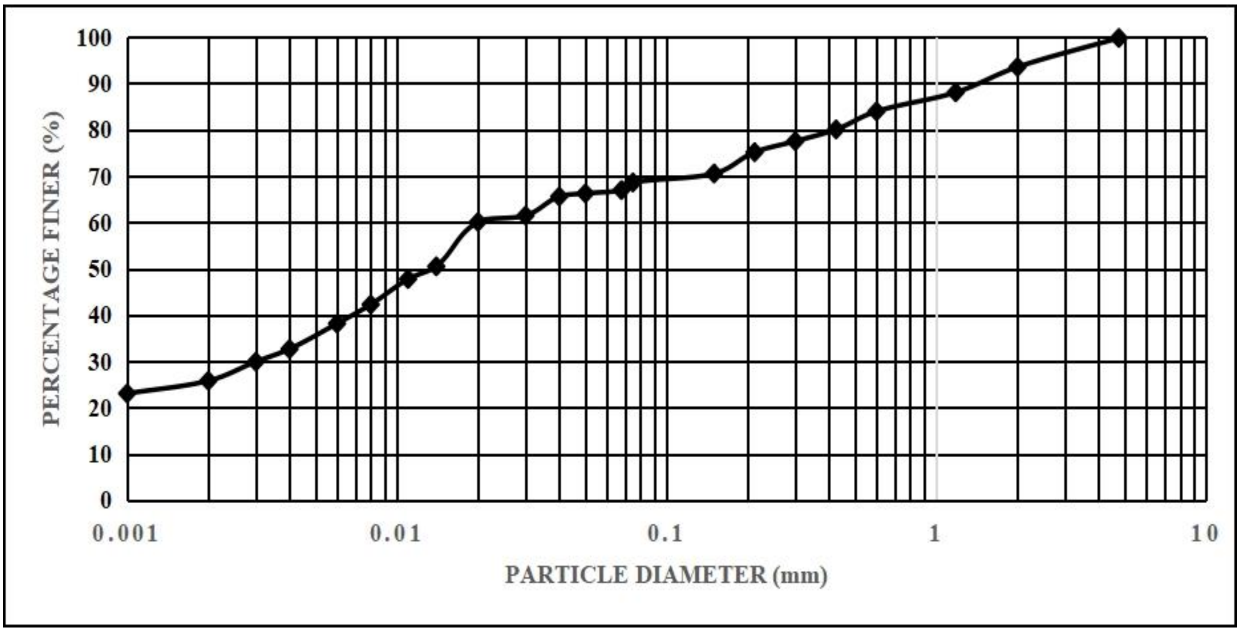

Figure 1: Particle Size Distribution Curve of the Natural Soil Sample

Table 1: Properties of the Natural Soil Sample

Property/Classification	Quantity
Percentage passing BS No 200 Sieve (%)	68.60
Natural moisture content (%)	16.73
Liquid Limit (%)	47.50
Plastic Limit (%)	26.95
Plasticity index (%)	20.55
Linear Shrinkage (%)	7.86
Specific gravity	2.65
AASHTO Classification	A-7-6
USCS Classification	CL
Group Index	14
Maximum Dry Density (mg/m^3)	-
British standard light (BSL)	1.68
Optimum Moisture Content (%)	-
British Standard Light	19.95
Ph	7.65
Colour	Brownish
Dominant Clay Mineral	Kaolinite

3.2 Compressive Strength Development

The incorporation of Makuba significantly enhanced compressive strength, with increases ranging from 25% to 60% relative to the control mix. Peak strengths exceeding 3.0 N/mm² were achieved, satisfying the Nigerian Industrial Standard for load-bearing blocks.

This improvement is attributed to a combination of physical and chemical mechanisms. The lignin-rich composition of Makuba promotes inter-particle bonding through hydrogen bonding and van der Waals forces, resulting in improved cohesion within the soil matrix [17]. Additionally, the fine organic particles act as fillers, reducing pore volume and enhancing packing density.

Similar strength enhancement trends have been reported in bio-stabilized systems incorporating agricultural waste materials, where pore refinement and improved matrix continuity contribute to increased load-bearing capacity [11,14].

However, excessive Makuba content resulted in marginal strength reduction. This behaviour is attributed to increased organic content, which may disrupt matrix continuity and introduce micro-voids, consistent with findings reported by Adesina and Olutoge [19]. Figure 2 below, shows the Compressive Strengths of Compressed Stabilized Soil Blocks.

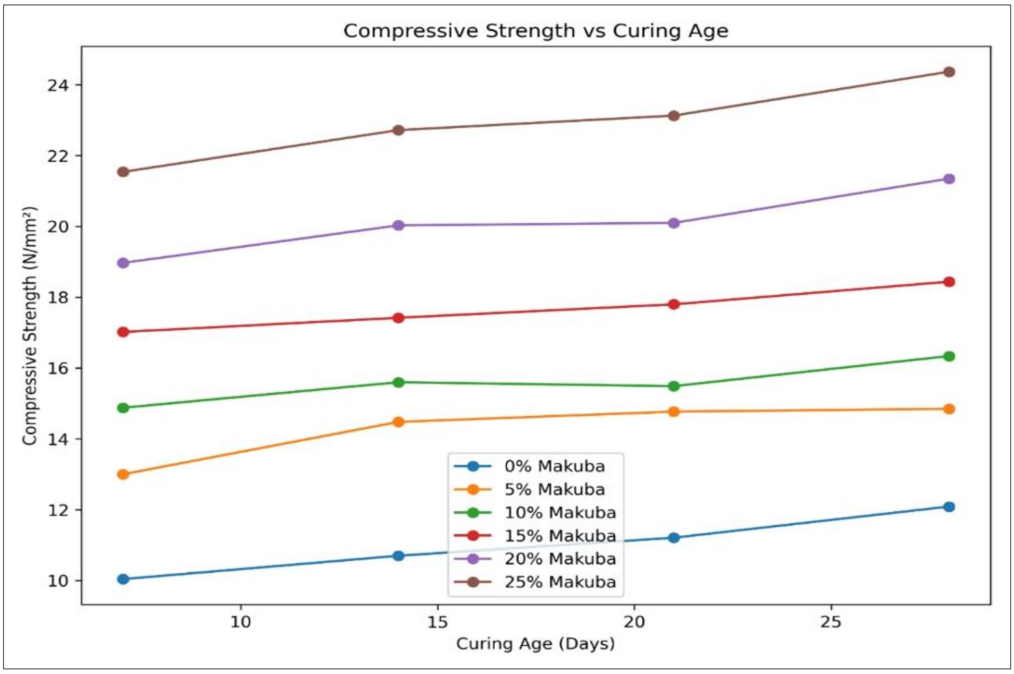

Figure 2: Compressive Strengths of Compressed Stabilized Soil Blocks

3.3 Water Absorption and Durability Behaviour

Water absorption decreased significantly with Makuba addition, with all stabilized samples achieving values below 12%, satisfying ASTM durability requirements [22].

The reduction in water absorption is primarily due to:

- Decreased pore connectivity
- Increased matrix densification
- Enhanced tortuosity of capillary channels

This behaviour aligns with previous studies on bio-stabilized materials, where organic additives contribute to pore blocking and reduced permeability [15,16].

The improved durability is particularly significant for tropical environments, where cyclic wetting and drying can lead to rapid deterioration of unstabilized materials. The reduction in water absorption directly correlates with improved resistance to environmental degradation [18].

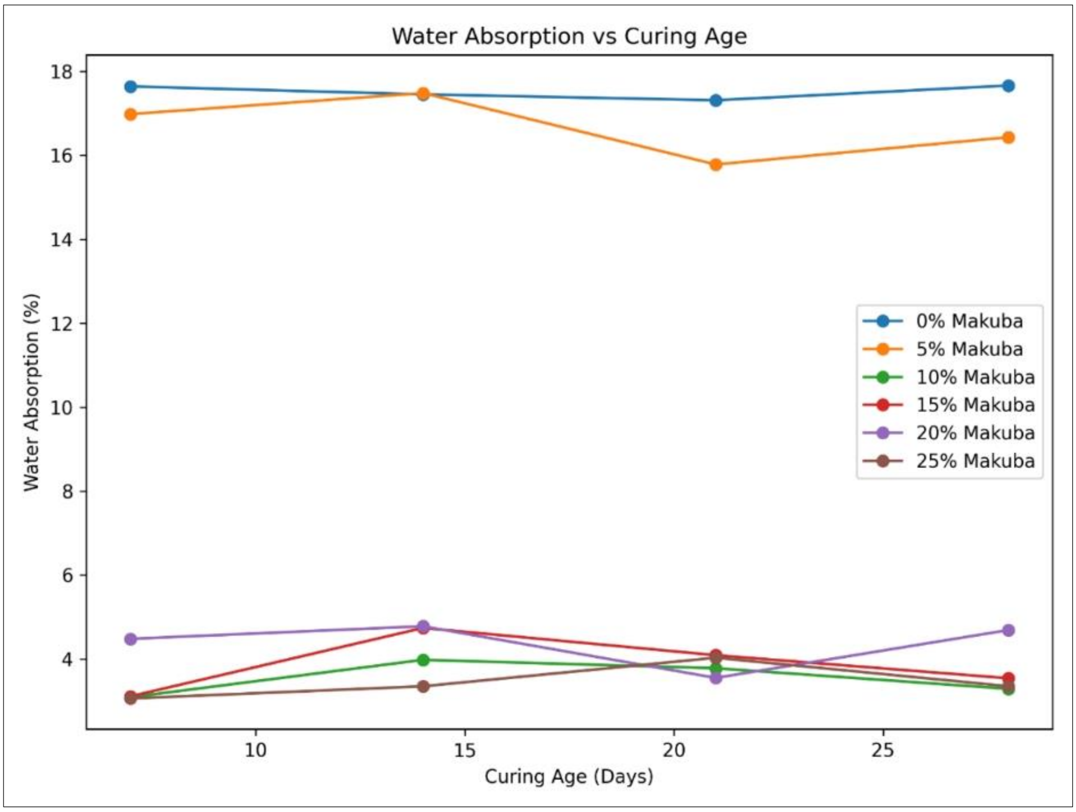

Figure 3: Water Absorption of Compressed Stabilized Soil Blocks

3.4 Microstructural Characteristics

Microstructural analysis provided critical insights into the stabilization mechanisms of Makuba. SEM images revealed a denser and more homogeneous matrix in stabilized samples compared to the control, with significantly reduced pore spaces and improved particle packing.

EDX analysis confirmed the presence of silica and alumina, indicating the potential for physicochemical interactions that contribute to matrix stabilization. XRD patterns revealed the presence of stable mineral phases, suggesting improved structural integrity.

The observed microstructural improvements can be attributed to:

- Formation of organic binding networks from lignins and polysaccharides
- Enhanced interfacial bonding between soil particles
- Reduction in pore connectivity and improved matrix continuity

These findings demonstrate a strong correlation between microstructural modification and macroscopic performance, particularly in terms of strength and durability. Similar behaviour has been reported in studies involving bio-based stabilizers, where organic compounds contribute to matrix densification and improved engineering properties [12, 18].

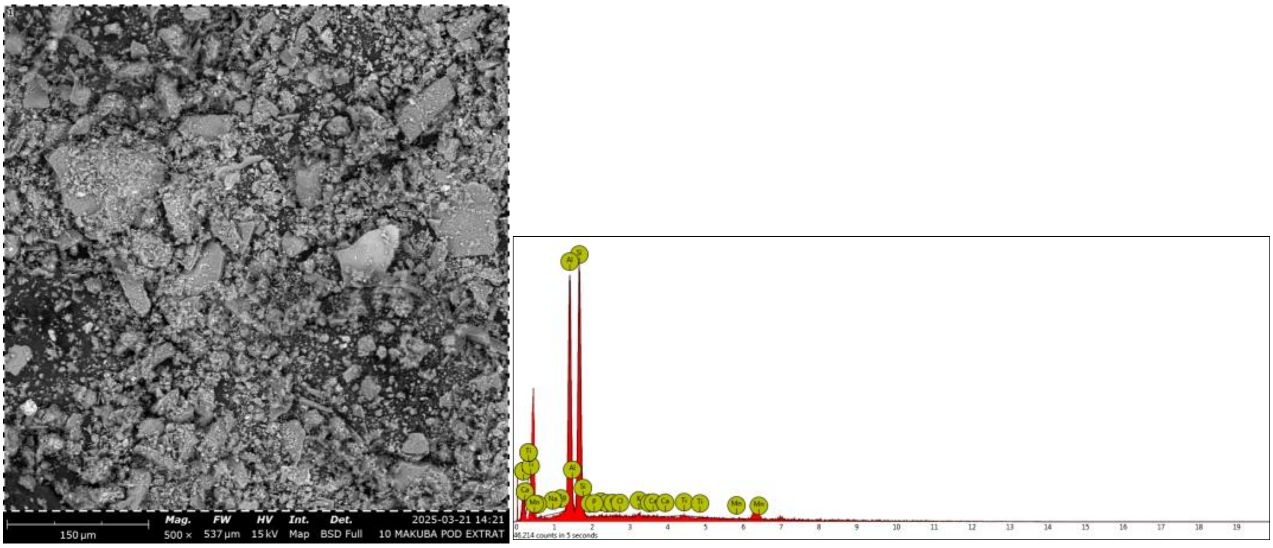

Figure 4: SEM and EDX of Makuba Pod Extract

4. CONCLUSIONS

The following conclusions are drawn from this study:

1. Makuba (*Parkia biglobosa*) is an effective bio-stabilizer for compressed earth blocks.
2. Compressive strength improved significantly, achieving values exceeding 3.0 N/mm² suitable for structural applications.
3. Water absorption decreased below 12%, confirming enhanced durability performance.
4. Microstructural analysis revealed improved particle bonding, reduced porosity, and enhanced matrix densification.
5. Optimal Makuba content is critical for achieving the best balance between strength and durability.
6. Makuba-stabilized CSEBs provide a sustainable and low-cost alternative to conventional cement-based masonry materials.

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