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Naturally Strengthening Rammed Earth: The Promising Potential of Biopolymers

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Abstract. Sustainable construction has become a global imperative due to the growing awareness of the harmful environmental impacts of the construction industry. The use of cement and lime in traditional methods of stabilizing earth constructions is a significant problem due to their high carbon footprint. This article examines an ecological alternative to stabilizing earth structures with biopolymers. These Bio-based materials can be used to reduce the environmental impact of the construction industry while also ensuring the structure's stability and durability. The purpose of this article is to examine the mechanical properties of biopolymers in the context of stabilizing earth construction. The objective is to guide the decision on which stabilization method to use for earth construction based on the available resources.

Introduction

Over the past few decades, extensive research has been undertaken on natural materials combined with unconventional technologies due to the growing emphasis on sustainability and the use of recyclable natural resources. The widespread availability, affordability, and ease of implementation have made earth construction more popular in this context. The materials are exceptional in terms of sustainability, with low energy consumption during production and high recyclability. The importance of earth construction can be seen in its applications in traditional architecture, modern low-cost social housing, and heritage restoration [1].

There are different earth construction techniques such as wattle and daub, cob, rammed earth (including earth shotcrete), as well as adobe bricks and compressed earth blocks (CEB).

It has been nearly six millennia since the adoption of the wattle and daub construction method [2], Involves compacting soil against a lattice made of interwoven wooden strips. Wattle and daub is similar to a technique called 'tabique' used in Portugal [3].

On the contrary, cob entails blending earth with straw and water to create layered walls [4].

Rammed earth involves compacting moist earth (stabilized or not) into a wooden formwork, while earth shotcrete involves pre-stabilizing the earth before spraying it onto an internal formwork. A blended earth wall system, incorporating aspects of rammed earth, cob, and wattle and daub, was recently employed in Portugal.

Adobe is an uncomplicated and age-old method of earth construction [5], uses wooden molds filled with wet earth, dried in the sun [6]. As adobe dries, surface shrinkage cracks may emerge, leading some authors [7,8] to propose the incorporation of straw or other vegetable fibers as a preventive measure.

Compressed earth blocks (CEB) represent an evolution of adobe bricks, compressing earth in a mold using a specific device, with manual or mechanical pressure. These blocks exhibit greater weight and strength compared to adobe bricks. Different machines, such as the CINVA-Ram, the Astram, Over the years, various machines such as the CETA-Ram, the Brepak multi-block, and

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the CTA Triple-Block Press have been developed for the production of Compressed Earth Blocks (CEB) [9].

Earth construction, while promising for its affordability and eco-friendliness, often relies on environmentally harmful chemical stabilizers like cement and lime. These materials create a double whammy for the environment: cement production spews large amounts of CO2, a major greenhouse gas, while lime extraction and processing are energy-intensive, further contributing to emissions. This dependence on chemical stabilizers also drains natural resources and worsens environmental degradation. To counteract this worrying trend, exploring and implementing sustainable alternatives for stabilizing earth constructions is crucial.[10,11]
Increasingly, scientific research is focusing on new and innovative stabilization pathways. Among these alternatives is:

Natural stabilization using biopolymers: Earthen constructions can be stabilized through the use of biopolymers, natural polymers produced by the cells of living organisms. These biopolymers bind to clay, imparting increased strength. They play an essential role in preserving and maintaining the durability of structures in the face of adverse weather conditions and other degrading factors. These diverse stabilization approaches offer varied solutions to reinforce earthen constructions, enhancing their resistance, durability, and environmental friendliness [12].

Biopolymers
Biopolymers are polymers of natural origin, often derived from renewable raw materials such as plant, animal, algal, fungal or bacterial sources. Their characteristics can be diverse, including plant or animal origin, hydrophilicity, hydrophobicity, or amphiphilicity.

According to Vissac and colleagues [13], biopolymers can be classified according to the nature of the molecule responsible for improving cohesion and the physico-chemical mechanisms involved.

Polysaccharides are complex carbohydrates made up of a large number of simple sugar molecules called monosaccharides, linked together by glycosidic bonds. These bonds are formed by the loss of a water molecule when two monosaccharide molecules are combined. The frequently encountered glycosidic bonds include α-1,4-, β-1,4-, and α-1,6-glycosidic [14]. A straight or branched chain can be connected to the structural unit. In the chain structure that is straight, the structural units are linked together by α-1,4- or β-1,4-glycosidic linkages (such as starch). In the branched structure, the structural units are linked together by α-1,6 glycosidic bonds (such as cellulose) [13,15].

There are two distinct categories of polysaccharides: heteropolysaccharides and homopolysaccharides. A single monosaccharide is what makes up the latter. for example, starch, cellulose, and glycogen. Heteropolysaccharides, on the other hand, are made up of several types of monosaccharide, as is the case with hyaluronic acid (HA), chondroitin and alginate. The latter can be classified according to two main roles: the structural function, observed in polysaccharides such as cellulose and chitin, or the energy storage function, illustrated by examples such as starch [16–18].

Polysaccharides can create microscopic reinforcements among clay particles, enhancing cohesion and making the soil stronger and more resistant. Additionally, they modify the consistency of fresh mortar, forming gels that improve adhesion and ease of application.

Lipids, including fats and other organic compounds, have low solubility in water and can be hydrophobic or amphiphilic based on their physical properties.

A chain of amino acids found in animals or plants is what proteins are made up of. Some play a structural role, such as collagen, which contributes to the formation of skin and bone, while others transport molecules, such as albumin, found in eggs and blood, and casein, found in milk [19].The functionality of a protein, determined by its surface characteristics, depends on the sequence of amino acids and their spatial organization [13].

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Their interaction with clays is significant: the hydrophilic parts adsorb onto fine clay particles, while the hydrophobic parts, which are repelled by water, move towards the outside of the clay particle, where they are protected from water. Proteins act as glues for clays and can also have a hydrophobic effect, reducing the water sensitivity of stabilised earth plasters [13,20].

Tannins, natural compounds found in plants, show promise for soil stabilization. Soluble in water, they act like "claws," capturing metal ions in clay soils, weakening ionic strength, and promoting clay dispersion. Additionally, tannins react with iron to release multivalent ions, enhancing attraction between clay platelets and improving water resistance. This dual action—dispersion through their structure and cohesion through released iron ions—positions tannins as a potential eco-friendly alternative to traditional chemical stabilizers for enhancing clay soil strength.

Biopolymer composites: A sustainable method for stabilizing soils

Earthen construction combines traditional methods with modern mechanical testing, relying on factors like soil composition and moisture for stability. The integration of biopolymers is pivotal for soil stabilization, offering eco-friendly solutions that enhance cohesion and strength. This innovative approach aligns with sustainable practices and has the potential to revolutionize traditional methods in earthen construction.

Polysaccharides

The study conducted by C. Galán-Marín et al.[21] aims to stabilize soils using polymers and natural fibers to create a durable, non-toxic, and locally sourced composite construction material. Compression tests reveal significant results, showing a marked improvement in compression strength with the addition of natural fibers such as wool and alginate. The synergistic combination of wool and alginate nearly doubles the soil's strength, providing promising prospects for practical applications in construction.

Another investigation led by Yahor Trambitski and his team [22] explores the compression strength of clay composites treated with biopolymer solutions, including starch, alginate, and chitosan. The results indicate an increase in compression strength with the addition of starch and alginate, while chitosan shows mixed results, suggesting a less effective interaction with clay particles. These studies present intriguing possibilities for the development of more sustainable and environmentally friendly construction materials.

Proteins

C. Kraus and coauthors [23] conducted tests, presenting results on the compressive strength of rammed earth stabilized with blood. The initial compressive strength of the control cylinders was 257 psi (1.77 MPa), exceeding that of the blood-stabilized cylinders, which measured 187 psi (1.29 MPa) after one week. However, by the fourteenth day, the blood-stabilized cylinders gradually narrowed the difference, reaching an average compressive strength of 518 psi (3.57 MPa), demonstrating comparability to the control group's 521 psi (3.59 MPa) with no statistically significant difference. By the twenty-eighth day, the blood-stabilized rammed earth exhibited a remarkable 36% improvement over the control, attaining a pressure of 973 psi (6.71 MPa), in contrast to the control group's 625 psi (4.31 MPa). This highlights the significant enhancement in compressive strength through blood stabilization, especially notable when compared to less reactive soils, where blood-stabilized samples exhibited over a 200% improvement over controls in a prior pilot experiment.

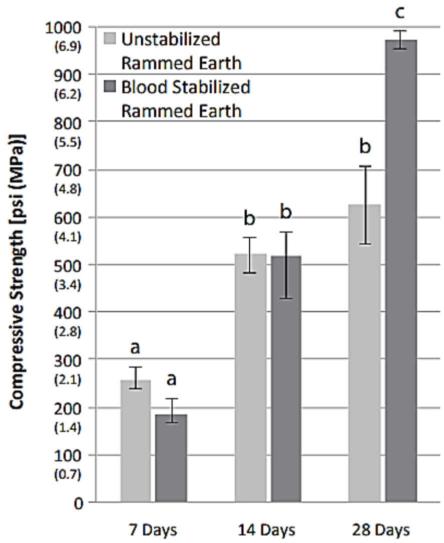

Fig. 1: *Comparing the compressive strength of unstabilized and blood-stabilized rammed earth [23].*

Complex molecules

Younoussa Millogo and colleagues [24] aimed to develop cost-effective, durable blocks with high water resistance and thermal properties conducive to superior indoor comfort. Figure 2 illustrates the variations in compressive strength relative to different levels of cow-dung content in adobes, showing a consistent pattern of increased mechanical parameters with higher cow-dung additions. The improved compressive strength is attributed to reduced porosity and crack prevention within the adobes. Figure 3 establishes a correlation between compressive strength and water absorption, indicating a robust connection. The introduction of cow dung enhances compressive strength by reducing porosity through microbial debris and amine organic compounds. The non-digested fibers enhance adhesion to the clay matrix, creating a rough surface that inhibits crack propagation. Additionally, the silicate amine formed in the fermentation process binds soil particles together, reducing pore size and number, ultimately boosting compressive strength.

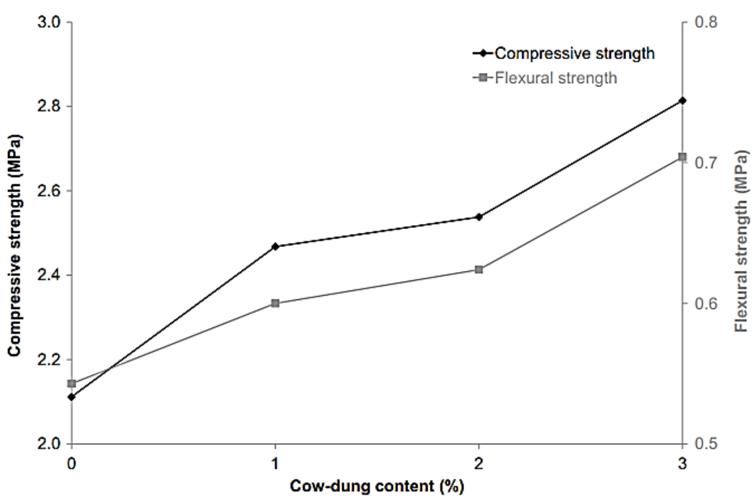

Fig. 2: *The evolution of the flexural and compressive strength of adobes has been influenced by the content of cow dung [24]*

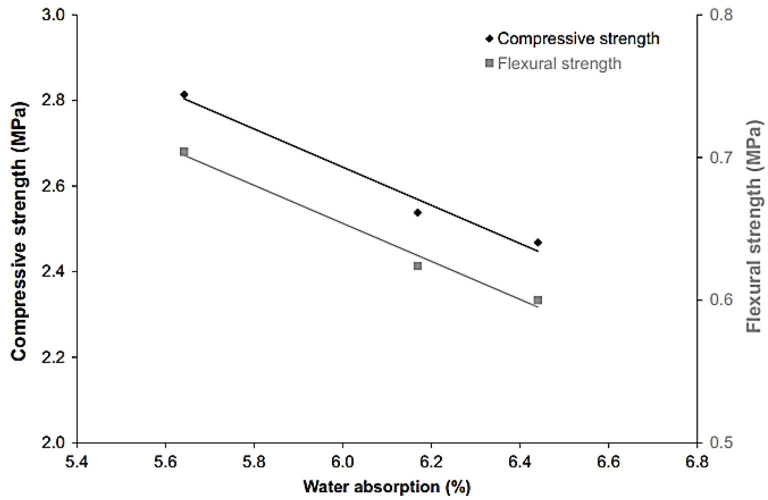

Fig. 3: *The correlation of water absorption and compressive (or flexural) strength in adobes [24]*

Conclusion

In summary, the integration of diverse biopolymers—polysaccharides, lipids, proteins, and tannins—provides a sustainable and multifaceted approach to soil stabilization in earthen construction. These natural compounds enhance soil cohesion, strength, and water resistance while offering eco-friendly alternatives to traditional stabilizers.

Studies, such as those by C. Galán-Marín and Yahor Trambitski, highlight the efficacy of biopolymer composites, incorporating materials like wool and alginate, to significantly improve compression strength. The innovative use of blood-stabilized rammed earth by C. Kraus demonstrates a remarkable 36% improvement in compressive strength over traditional methods.

Younoussa Millogo's work introduces cost-effective, durable blocks with enhanced water resistance through the incorporation of cow dung, showcasing the transformative potential of biopolymers in construction methodologies.

In essence, the integration of biopolymers presents a sustainable and transformative force in soil stabilization, shaping a more resilient and eco-friendly future for earthen construction.

In perspective, a promising avenue for future research would involve exploring the synergistic combination of various biopolymers to further optimize the properties of earthen construction materials. This approach could potentially lead to significant advancements, further enhancing the cohesion, strength, and durability of these materials, thereby opening new possibilities for more sustainable and environmentally friendly construction solutions.

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