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Analysis of Earth Bricks from Huimanguillo, Tabasco, Mexico: Physical and Mechanical Properties for Construction Applications

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Abstract This study evaluates the physical and mechanical properties of three soil samples collected from distinct locations in Huimanguillo, Tabasco, Mexico, to assess their suitability for sustainable construction. The soils were classified as medium plasticity clay (CL) and high plasticity clay (CH) according to the Unified Soil Classification System (USCS). Physical properties, including bulk density, moisture content, plasticity, and linear shrinkage, were measured, revealing significant variability that was influenced by mineral composition and geographical origin. Grain size distribution analyses indicated that all samples passed the No. 4 sieve (98–100%), with notable differences in finer distributions across the samples. The load-bearing capacities of bricks made from these soils—both with and without the addition of 20% fine sand—were evaluated. Bricks without additives demonstrated significantly higher compressive strength, with Sample No. 2 achieving 320.0±5.8 g/mm², indicating its potential for structural applications. In contrast, bricks containing fine sand exhibited reduced strength but improved workability, making them more suitable for non-structural uses. These findings highlight the feasibility of using locally sourced soils for sustainable construction, particularly in regions with limited access to industrial building materials. The study underscores the importance of optimizing soil composition to balance strength, workability, and durability, offering cost-effective and eco-friendly architectural solutions for housing and urban infrastructure: the use of locally sourced soil for construction, such as compressed earth blocks, offers significant ecological benefits by reducing carbon emissions, promoting circular economy principles, and conserving natural resources.

Keywords Sustainable Practices, Local Material Optimization, Mechanical Performance, Vernacular Architecture Techniques

1. Introduction

The construction industry increasingly explores alternative materials to promote sustainable building practices, with some regions being rich in locally available natural soils as a resource. Unfired earth bricks, as opposed to fired ceramic units, offer a promising solution due to their affordability, low environmental impact, and adaptability to local conditions [1]. Huimanguillo, a municipality in Tabasco, Mexico, possesses abundant soil resources with potential for brick manufacturing. However, a detailed understanding of the physical and mechanical properties of these soil bricks is essential for their effective application in construction projects. This study aims to investigate these properties through comprehensive testing and analysis.

The use of soil as a construction material has a history rooted in ancient civilizations, such as Mesopotamia and Egypt, where its sustainability and durability were demonstrated in vernacular architecture [2, 3]. Modern sustainability challenges have reignited interest in earthen construction, emphasizing its potential to reduce carbon emissions in the building sector [4, 5]. Soil-based structures, such as adobe and rammed earth, are increasingly recognized for their environmental benefits, particularly in the context of a circular economy [6].

The properties of soil, including composition, particle size distribution, and plasticity, significantly influence the quality of soil-based bricks [7]. Proper characterization of these properties is crucial to ensuring the structural integrity and performance of construction elements [8]. Furthermore, soil characteristics vary geographically, necessitating site-specific studies to optimize material selection and usage [9]. Huimanguillo, located in southern Mexico, is renowned for its fertile soils, predominantly clayey in nature, making them suitable for brick production [10, 11]. However, regional variations in soil properties may affect their suitability for construction purposes [12].

Key physical properties, such as bulk density, particle size distribution, and moisture content, are fundamental to determining soil suitability for brick manufacturing [13]. Equally important are the mechanical properties of soil bricks, including compressive strength and load-bearing capacity, which are critical for structural stability [14]. These properties depend on factors such as soil composition, compaction methods, and curing conditions [15]. Recent studies highlight the potential of additives like lime, cement, and fibers to enhance the performance of soil bricks while maintaining sustainability [6, 16, 17]. Despite advancements in material optimization, the sustainable utilization of soil resources remains a pressing concern, underscoring the need for further research on locally available materials [18].

Huimanguillo's unique geographic and climatic conditions, including its tropical climate and proximity to water bodies, present both opportunities and challenges for soil-based construction. These factors can significantly influence soil properties, affecting the durability and performance of construction materials [19, 20]. Vernacular architectural practices in similar contexts provide valuable lessons for addressing these challenges, integrating low-carbon and resource-efficient techniques [3, 21].

This study aims to address the knowledge gap regarding the physical and mechanical properties of soil bricks from Huimanguillo, Tabasco, Mexico. By conducting comprehensive testing and analysis, it seeks to provide insights into the suitability and performance of local soil resources for sustainable construction. The findings are expected to contribute to the development of cost-effective and environmentally friendly building solutions tailored to the region’s specific conditions [22, 23]. This work aligns with global efforts to promote sustainable design and circular economy principles in construction [2, 4].

2. Materials and Methods

The soil samples were collected from three distinct locations in Huimanguillo, Tabasco, Mexico, and labeled as No. 1, No. 2, and No. 3. Sample No. 1, sourced from Monte de Oro (latitude 17.888642˚, longitude -93.436408˚), Samples No. 2 and No. 3, were collected from C-41 (latitude 17.936030˚, longitude -93.448212˚) and Tierra Nueva Segunda Sección (latitude 17.799987˚, longitude -93.468520˚), respectively.

To ensure the accuracy and reliability of the results, each sample underwent eight testing. Various tests were conducted to evaluate the physical and mechanical properties of the soil, including bulk density, moisture content, particle size distribution, plasticity index, linear shrinkage, and classification according to the Unified Soil Classification System (USCS) (ASTM D2487, 2017). Following the methodology outlined by Velasco-Aquino [12], compressed earth blocks were produced from the soil samples, both with and without the addition of fine sand. The blocks were further tested to assess their load-bearing capacity under different compositions and conditions, allowing for a detailed evaluation of the impact of soil composition on the mechanical performance of the blocks.

Figure 1 shows the location of the earth obtention zone.

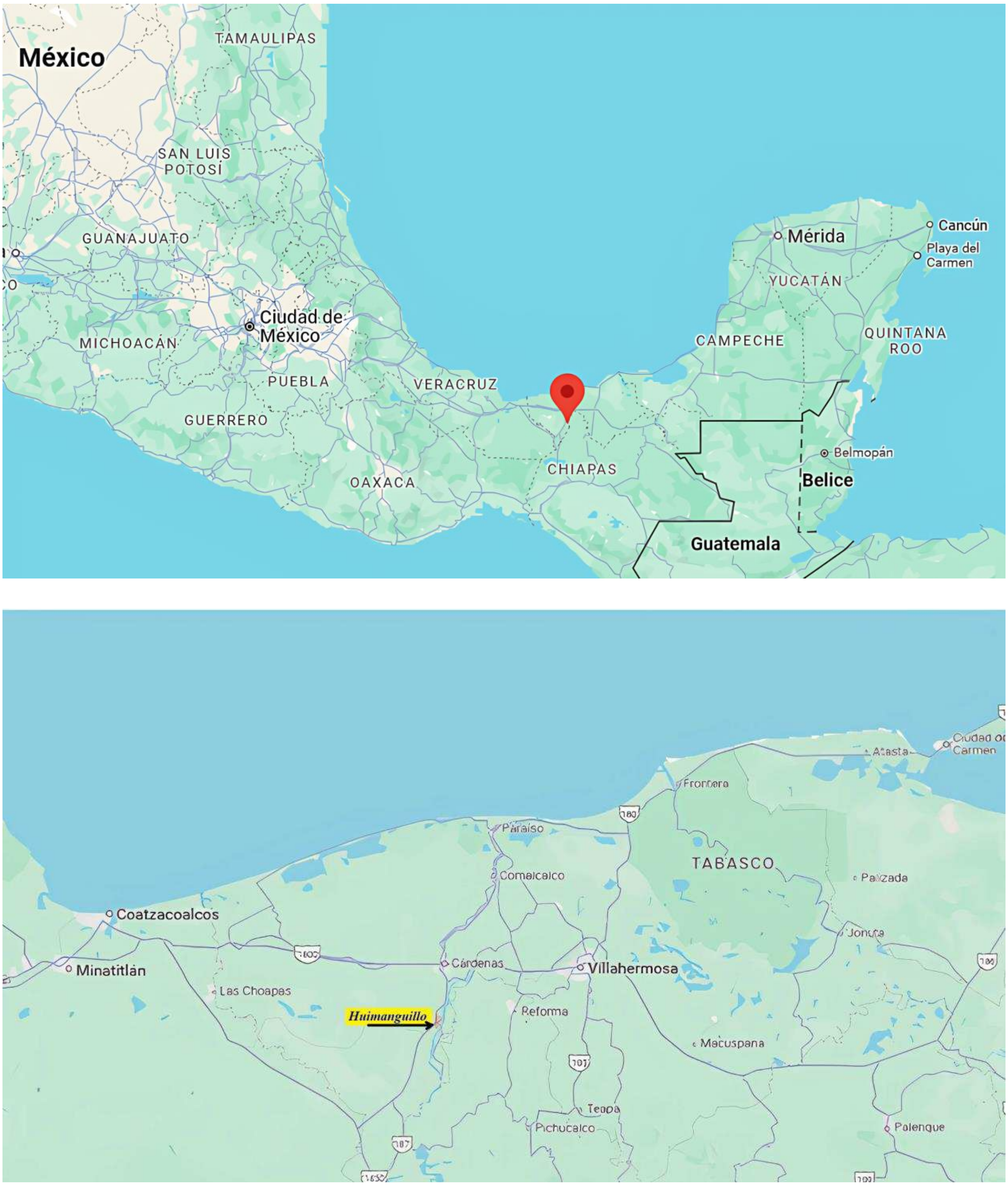

Figure 1. Location of the earth samples (Red point) and magnification (down)

3. Results and Discussion

The results presented are averages obtained from eight replicates for each test, ensuring statistical reliability and consistency. The standard deviations, shown as absolute values, ranged between 1.2% and 3.0%, demonstrating high precision in the measurements.

3.1. Physical Properties of Soil Samples

The physical properties of the soil samples varied significantly, reflecting differences in mineral composition and environmental conditions at the three collection sites. Table 1 summarizes the physical properties of the samples, highlighting variations in bulk density, moisture content, plasticity, and linear shrinkage.

Table 1. Physical Properties of Soil Samples

Sample	Classification	Bulk Density (kg/m^3)	Optimum Moisture Content (%)	Liquid Limit (%)	Plasticity Index (%)	Linear Shrinkage (%)
No. 1 (Monte de Oro)	Medium plasticity clay (CL)	1134 ± 27	16.8 ± 0.3	44.0 ± 1.0	20.25 ± 0.31	10.36 ± 0.21
No. 2 (C-41)	High plasticity clay (CH)	1034 ± 21	18.5 ± 0.5	60.0 ± 1.7	24.77 ± 0.52	12.19 ± 0.15
No. 3 (Tierra Nueva)	High plasticity clay (CH)	967 ± 29	15.7 ± 0.3	63.11 ± 1.9	24.34 ± 0.56	13.45 ± 0.36

- Sample No. 1 (Monte de Oro): This sample, classified as medium plasticity clay (CL), displayed the highest bulk density among the three samples (1134 ± 27 kg/m^3). Its relatively low optimum moisture content (16.8 ± 0.3%) and moderate plasticity index (20.25 ± 0.31%) suggest it is well-suited for use in construction applications where moderate shrinkage (10.36 ± 0.21%) is acceptable.
- Sample No. 2 (C-41): A high plasticity clay (CH) with a darker color, this sample had a lower bulk density (1034 ± 21 kg/m^3) but higher plasticity index (24.77 ± 0.52%) and linear shrinkage (12.19 ± 0.15%). These properties suggest better cohesion but increased susceptibility to cracking during drying or curing, a critical factor to consider in brick manufacturing.
- Sample No. 3 (Tierra Nueva): Also classified as high plasticity clay (CH), this sample exhibited the lowest bulk density (967 ± 29 kg/m^3) and the highest linear shrinkage (13.45 ± 0.36%). These characteristics could limit its direct applicability in high-load scenarios unless stabilized with additives or mixed with other materials.

3.2. Grain Size Distribution

The particle size distribution (Table 2) indicates that all samples passed through the No. 4 sieve at high percentages (98–100%), confirming their suitability for fine-grained applications. However, differences emerged at finer sieve levels, with Sample No. 3 showing the coarsest distribution (76.0 ± 1.5% passing the No. 200 sieve) compared to Samples No. 1 (93.7 ± 1.0%) and No. 2 (96.0 ± 1.3%). These differences affect the soil's texture and workability, critical parameters for brick and block production.

3.3. Load-Bearing Capacity of Manufactured Bricks

The compressive strength of bricks varied depending on the soil composition and whether fine sand was added (Table 3).

Bricks with 80% Soil and 20% Fine Sand: The load-bearing capacities were relatively low, ranging from 50.40 ± 1.51 g/mm^2 (Sample No. 3) to 61.49 ± 1.17 g/mm^2 (Sample No. 2). These results indicate that adding fine sand reduces compressive strength, likely due to decreased cohesion.

Bricks Without Additives: Bricks made solely from soil exhibited significantly higher load-bearing capacities, with Sample No. 2 achieving the highest value (320.0 ± 5.8 g/mm^2), followed by Sample No. 1 (267.3 ± 6.4 g/mm^2). These results underscore the potential of unaltered soil for structural applications, especially when using high-plasticity clay like those found in Samples No. 2 and No. 3.

3.4. Other Observations

The observed differences in soil properties are closely linked to the geographic and mineralogical characteristics of each sampling location. Samples No. 2 and No. 3, classified as high plasticity clay, exhibited higher shrinkage and lower dry densities, which can be attributed to their higher clay content and organic matter. This aligns with findings from studies highlighting the influence of clay content on cohesion and volumetric behavior [2].

Bricks manufactured without additives demonstrated significantly higher load-bearing capacities compared to those with fine sand, indicating a compromise between strength and workability. Previous research, such as [12], has shown that while additives like fibers and stabilizers can enhance durability and resistance to environmental factors, they may also alter the compressive strength.

Furthermore, the addition of fine sand reduced shrinkage but slightly compromised compressive strength. This result underscores the importance of tailoring material compositions for specific construction applications, as noted by Morel et al. [4]. For instance, bricks with added sand may be more suitable for non-load-bearing structures due to their improved dimensional stability.

Overall, the findings highlight the potential for utilizing local soil resources in sustainable construction, particularly when adjustments are made to balance strength and workability. Future research should explore the incorporation of organic or waste-derived stabilizers, aligning with circular economy principles in earthen architecture [6, 17].

Table 2. Grain Size Distribution

Sample	Passing No. 4 Sieve (%)	Passing No. 40 Sieve (%)	Passing No. 200 Sieve (%)
No. 1 (Monte de Oro)	100	98.7 ± 1.0	93.7 ± 1.0
No. 2 (C-41)	100	98.0 ± 1.3	96.0 ± 1.3
No. 3 (Tierra Nueva)	98	88.0 ± 1.5	76.0 ± 1.5

Table 3. Comparative Load-Bearing Capacity of Manufactured Bricks

Sample	Load-Bearing Capacity (N/mm^2) with 80% Soil and 20% Fine Sand	Load-Bearing Capacity (N/mm^2) without Additives
No. 1 (Monte de Oro)	**0.5618 ± 0.0118**	**2.6222 ± 0.0628**
No. 2 (C-41)	**0.6032 ± 0.0115**	**3.1392 ± 0.0570**
No. 3 (Tierra Nueva)	**0.4944 ± 0.0148**	**1.1007 ± 0.0275**

This comprehensive characterization of Huimanguillo soils provides valuable insights into advancing sustainable building practices in regions with similar conditions, that is, these findings emphasize the potential of utilizing local soils in construction, offering cost-effective and environmentally friendly solutions for housing and urban development

3.4.1. Impact of Sand Additions on Workability and Mechanical Properties of Bricks

Incorporating fine sand into brick production enhances workability by facilitating molding and minimizing shrinkage during the drying process. However, this improvement does not lead to better load-bearing performance, as demonstrated in Table 3. The decline in compressive strength observed in bricks with 20% fine sand likely results from reduced cohesion within the soil structure. The presence of fine sand particles interferes with the natural bonding between clay particles, weakening the overall material strength under pressure.

While improved workability is beneficial for handling and shaping bricks, the reduction in compressive strength suggests that adding fine sand alters the mechanical properties of clay in a way that makes it less suitable for structural applications. This effect is particularly evident in high-plasticity clays, where clay content significantly contributes to cohesion and mechanical strength.

These findings raise questions about how the dimensional changes observed in modified clays, such as reduced shrinkage, might influence other properties. For example, greater dimensional stability could make sand-modified bricks better suited for non-load-bearing applications where uniformity and resistance to cracking are priorities, such as in partition walls or decorative features.

3.5. Environmental and Ecological Implications

The use of locally sourced soil for construction, particularly in the form of compressed earth blocks (CEBs), offers numerous ecological and environmental benefits. One of the most significant advantages is the reduction of the carbon footprint associated with conventional building materials such as cement and steel. The production of these materials requires substantial energy consumption, resulting in high CO_2 emissions. In contrast, using natural soil requires minimal processing, making it an environmentally friendly alternative that aligns with sustainability goals. The low energy demands of soil-based construction materials can significantly contribute to lowering greenhouse gas emissions in the built environment.

Additionally, soil-based construction promotes the concept of circular economy principles. Soil is a renewable resource that can be locally sourced, reducing the need for long-distance transportation, which further mitigates carbon emissions. The production of compressed earth blocks, especially when stabilized with natural additives like lime, aloe vera, or fibers (e.g., coconut), minimizes the consumption of non-renewable resources. Moreover, the use of natural soil for construction helps conserve forests and other natural habitats by reducing the need for timber and other deforestation-related materials.

From an ecological perspective, this approach fosters a more harmonious relationship between human development and the natural environment. It allows for the reuse of local materials, reducing waste and minimizing the extraction of raw materials that can degrade ecosystems. Furthermore, soil-based construction techniques, especially when combined with sustainable building practices, can help improve the resilience of buildings to environmental stresses, such as extreme weather events, by using materials that naturally regulate humidity and temperature.

Incorporating these practices into mainstream architecture can help create more sustainable urban environments, reduce reliance on industrial materials, and contribute to a lower ecological footprint, making them a vital part of future building practices for addressing global environmental challenges.

3.6. Study Limitations

Although the analysis of the physical and mechanical properties of the soils was conducted using internationally recognized standardized methods (ASTM D2487, 2017), this approach presents inherent limitations. Standardized tests, while ensuring consistency and comparability, may not fully capture specific variations associated with local conditions or external factors, such as detailed mineralogical composition or the influence of the environment on material behavior. To address these limitations, methodologies tailored to local conditions were incorporated, including the production of compressed earth blocks following the protocol outlined at [12]. Additionally, the results were supplemented with a critical analysis of the soil's contextual properties, including variations in clay and organic matter content, providing a more comprehensive understanding of its applicability in construction. These adaptations aim to overcome the constraints of standardized methods, enabling a more holistic evaluation of the potential of local soils for sustainable applications.

4. Conclusions

This study presents a detailed evaluation of the physical and mechanical properties of soils from Huimanguillo, Tabasco, Mexico, to determine their potential for sustainable construction using compressed earth blocks (CEBs). The findings reveal significant differences among the soil samples. Sample No. 1 exhibited medium plasticity, while Samples No. 2 and No. 3 were classified as high plasticity clays. These distinctions, driven by mineral composition and geographic factors, directly influenced key properties such as workability, compressive strength, and shrinkage.

The analysis of load-bearing capacities showed that bricks made from untreated soil outperformed those incorporating fine sand in terms of compressive strength. Specifically, Sample No. 2 demonstrated the highest load-bearing capacity among all samples, followed by Sample No. 1. Meanwhile, Sample No. 3 had the lowest strength, despite sharing similar high plasticity characteristics with Sample No. 2. This outcome highlights the critical interplay between soil composition, plasticity, and mechanical performance, where optimal plasticity and mineral balance enhance structural properties.

From an ecological perspective, the use of locally sourced soil for construction aligns with sustainable building practices, offering a low-carbon alternative to traditional materials like cement. By minimizing energy consumption and supporting circular economy principles, soil-based construction reduces environmental impacts while promoting resource efficiency. Additionally, this approach contributes to local economic development by utilizing readily available materials.

These results underscore the viability of compressed earth blocks as a sustainable, cost-effective solution for housing and infrastructure in regions with abundant soil resources. Future research should focus on refining material compositions, incorporating stabilizers to enhance durability, and expanding the applicability of soil-based construction in diverse architectural contexts.

Further studies are needed to examine the impact of these dimensional changes on factors like durability, water absorption, and thermal performance. Additionally, investigating alternative additives or blended material compositions could help achieve a more favorable balance between workability, strength, and dimensional stability, supporting the development of versatile and sustainable construction materials.

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