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Enhancing Compressed Earth Block Performance: Effects of Gelatinized Starch and Fiber Reinforcement on Mechanical Properties

Bailly G.C [1,2], El Mendili Y. [1,*], Konin A. [2], Khoury E. [1]

1 Institut de Recherche, ESTP, F-94230 Cachan, France.
2 Laboratoire des Sciences Géographiques, du Génie Civil et des Géosciences, INP-HB, Côte d'Ivoire.
* Corresponding author: yelmendili@estp.fr

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Abstract. This study investigates the impact of starch stabilization and fiber reinforcement on the mechanical properties of Compressed Earth Blocks (CEBs). Various stabilization methods were tested to enhance the mechanical performance of CEBs, with a focus on starch as a natural binder and the incorporation of hemp as natural fibers. The research findings indicate that while starch slightly reduced internal cohesion by 13%, the addition of fibers alone significantly improved compression resistance by increasing strength by a factor of 3.57. When combined with starch, the effectiveness of fibers on compression resistance slightly decreased to a factor of 3.21. Cement stabilization, though providing the highest strength with a factor of 7, poses greater environmental challenges due to its high energy consumption and carbon emissions. In contrast, starch and natural fibers offer promising, eco-friendly alternatives that enhance CEB performance while reducing environmental impact. This study highlights the potential for integrating sustainable materials into construction practices to meet both structural and environmental objectives.

Key words: Compressed Earth Blocks, Starch Stabilization, Fiber Reinforcement, Mechanical Properties, Sustainable Construction.

1. Introduction

The durability of constructions is a concept that is gaining increasing importance in the current context of the climate crisis and the scarcity of natural resources. As the construction industry is one of the largest consumers of raw materials and a significant contributor to greenhouse gas emissions, it is imperative to explore more sustainable building practices. By opting for environmentally friendly materials and eco-responsible construction techniques, it is possible to not only reduce our carbon footprint but also contribute significantly to the preservation of ecosystems. Moreover, sustainable construction methods often result in improved energy efficiency, leading to a reduction in long-term energy costs for homeowners and contributing to the overall goal of energy conservation.

Traditional construction materials such as cement generate a significant amount of CO2 throughout their production chain. Cement production has far-reaching environmental consequences. It stands as the third-largest industrial source of air pollution, releasing harmful emissions that affect both the environment and human health. If the cement industry were considered a country, it would rank as the fourth-largest emitter of greenhouse gases in the world (Tang et al., 2022). The impact of cement production contributes to more than 7% of annual anthropogenic greenhouse gas (GHG) emissions, highlighting the urgent need for alternative building materials that are both sustainable and efficient (Miller et al., 2021).

In response to these challenges, exploring the use of natural and renewable resources in construction has become increasingly relevant. By replacing cement with organic binders such as starch and incorporating natural fibers like hemp as reinforcement, stabilized and reinforced earth construction offers a viable alternative (Bumanis et al., 2020). This approach not only reduces the environmental footprint of construction but also has the potential to enhance the mechanical properties and resilience of building materials (Tourtelot et al., 2023). Stabilized earth constructions can thus serve as a model of resilience and durability, essential for ensuring a habitable and sustainable future for generations to come.

The aim of this work is therefore to mechanically characterize compressed earth blocks, stabilized with an organic binder such as starch and reinforced with natural fibers such as hemp. Through this study, we seek to explore the potential of these bio-based materials in creating a sustainable and resilient construction solution that meets the demands of modern building practices while minimizing environmental impact.

2. Experimental program

2.1. Soils

The soils used in this study are of two types whose origin is France:

- Quarry soil from Vrignaie in Vendée,
- Clay soil excavated from the site of the Gustave Eiffel University at Champs-sur-Marne and provided by the Laboratory of Soil, Rock, and Structure Research (SRO).

After drying in an oven at 105°C for 48 hours, the soils were ground using a RETSCH BB50 crusher, followed by screening with square mesh sieve of 2-mm openings. The particle size distribution (Figure 1) of each soil was determined by wet sieving, followed by laser granulometry using a Beckman Coulter LS 1332 XR laser granulometer.

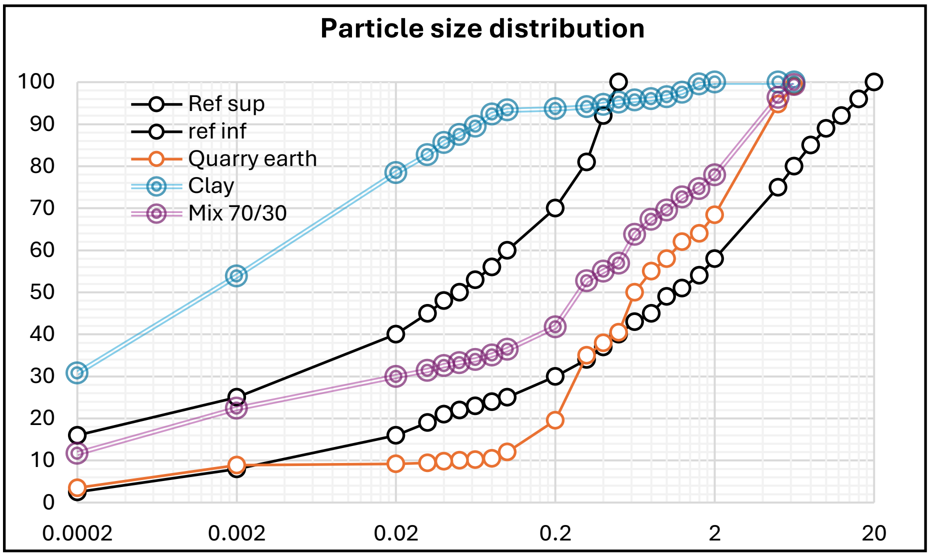


Fig 1. Granular distribution of soils and 70/30 mixture.

Based on the particle size distribution curves, we observe that both the quarry soil from Vrignaie in Vendée (SV) and the clay from Champs-sur-Marne (SCM) provided by Gustave Eiffel University do not fall within the granulometric range recommended by CRAterre (Ref inf and Ref sup in Fig 1). To address this, a physical stabilization was performed by mixing the two soil types. The optimal mixture that meets the recommended range consists by mass of 70% quarry soil from Vendée and 30% clay from Champs-sur-Marne. This mixture will be referred to as Mix 70/30 in this study.

The percentages of the components (sand, silt, and clay), based solely on the particle size distribution of the soils and Mix 70/30, are listed in Table 1.

Table 1. Mass percentage of sand, silt and clay elements in soils.

Soils	Sand (%) 0.063 < Ø < 2mm	Silt (%) 0.063 < Ø < 2mm	Clay (%) Ø < 0.002 mm
SV	89.82	1.31	8.87
SCM	10.50	35.63	53.87
Mix 70/30	66.02	11.61	22.37

2.2. Cement, starch and fiber

To evaluate the effect of the alternative binders, compressed earth blocks (CEBs) stabilized with cement were produced as a reference. The cement used is a CEM I 52.5, with a mass percentage of 5% based on the dry soil. The mineralogical characteristics of the cement are listed in Table 2.

The starch used is an organic starch powder purchased commercially (Figure 2).

The fibers incorporated into the soil for reinforcement are hemp fibers cut to a length of 3 cm and used in bulk in the mixture (Figure 2).

Table2. Chemical composition of cement by weight (%)

SiO_2	Al_2O_3	CaO	Fe_2O_3	SO_3	MgO
15.12	3.94	68.54	4.16	4.40	1.70
Na_2O	P_2O_5	K2O	TiO_2	SrO	PF
0.50	0.04	0.98	0.33	0.09	0.20

2.3. Formulation of Compressed Earth Blocks (CEB)

Five types of compressed earth block where formulated:

- Unstabilized compressed earth blocks contain.
- Cement-stabilized compressed earth blocks.
- Starch stabilized earth blocks ($BS_{2.5}$)
- Fibers reinforced earth blocks ($BRF_{0.5}$)
- Starch stabilized and fiber reinforced earth blocks ($BS_{2.5}F_{0.5}$)

The starch was pre-gelatinized by cooking at 70°C with a starch-to-water ratio of 0.2.

2.3. Block presses

The blocks were manufactured using a Multimeco MQ06-V4 press (Figure 2). This equipment features a loading hopper that allows the mold to be leveled during the return cycle. A pressure of 150 bars is then applied for 60 seconds before expelling the brick using a piston system located under the mold. After curing and drying (section 3.2), the blocks are subjected to compression using a Syntax 3R press (Figure 2) equipped with a 300 kN sensor, according to ASTM C67-07 standards. All block weighing operations were conducted with a precision balance (Figure 2) with a capacity of 15,000 ± 0.1 grams. Dimensions were measured using a tape measure.

Fig.2 a) Syntax 3R press, (b) Mecopress MQ06-V4, (c) Precision balance

3. Results and discussion

3.1. Geotechnical results

The liquid limit, plastic limit, and plasticity index (PI) partially determine the changes in the mechanical, thermal, and acoustic performance of the block. For blocks made with SCM, the water requirement to achieve better consistency also affects drying shrinkage, which can be improved by curing conditions. The liquid limits of SV and SCM are 31.03% and 72.93%, respectively, while the plastic limit of SV could not be determined. The plasticity index of TCM is 40.52%, which results in a plastic limit of 32.41%.

3.2. Curing conditions

The Compressed Earth Blocks (CEBs) underwent two main types of curing and drying:

- A 48-hour curing in the laboratory (T = 20°± 2°C and RH = 50 ± 5%) followed by drying at room temperature,
- A complete curing-drying in the laboratory conditions for 28 days.

The blocks exhibit a more consistent appearance and less mass loss when kept in the laboratory for 28 days compared to those that were dried at room temperature. Controlled humidity and stable temperatures in the laboratory enable uniform and gradual drying of the blocks. Thus, the stresses and deformations in the blocks resulting from drying-induced cracks are better managed in the laboratory environment. At room temperature, rapid variations (see Figure 3) can cause mechanical stresses, which may lead to deformations or fractures in the block structure (Izemmouren et al., 2013).

Fig.3 CEB outdoor drying temperature (july 2024)

3.2. Density and compressive strength of CEB

The wet weight of the blocks corresponds to their weight immediately after fabrication, while they still contain water, whereas the dry weight is measured after complete drying (28 days of age), when the water has evaporated (the mass variation between two weighings spaced 24 hours apart is less than 0.1%).

The density of the CEB is an essential parameter, defining the ratio between the mass and the volume of the blocks. It is calculated by dividing the dry mass by the block's volume and comparing it to the density of water.

The mass loss due to drying is the difference between the wet and dry weights and indicates the amount of water that has evaporated. This quantity strongly depends on the storage conditions of the blocks.

Finally, the compressive strength of the CEB is a key mechanical property, measuring the blocks' ability to withstand loads without breaking. This strength depends on the soil composition, the stabilization methods including the pressing level, and the residual moisture content after drying (Bailly et al., 2024).

These data are recorded in Table 3.

Table 3. Density and compressive strength of CEB

Ref	Moist average weight (g)	Medium weight (g)	Loss of mass (%)	Density (kg.m^{-3})	Compressive strength (MPa)
UB	6,384	5,602	12.24 %	1,713	1.00
BRC$_5$	7,472	6,693	10.42 %	1,993	7.58
BRF$_{0.5}$	7,080	6,189	12.58 %	1,939	3.57
BS$_{2.5}$	5,900	5,034	14.67 %	1,577	0.87
BS$_{2.5}$F$_{0.5}$	6,948	5,775	16.88 %	1,970	3.21

To enhance this strength, fibers have been incorporated into the earth mixture. The strength increased by a factor of 3.5, reaching 3.57 MPa.

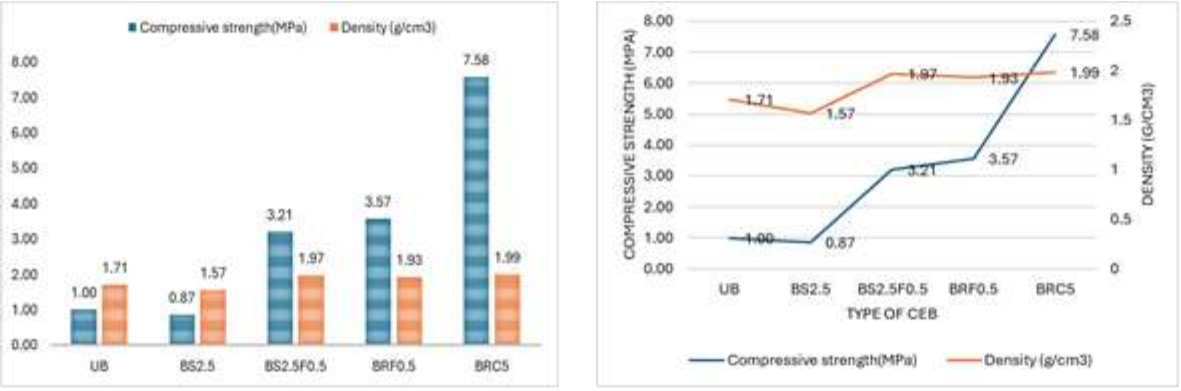
Incorporating fibers into the CEBs is a proven method to reinforce these materials (Taallah et al., 2014; Paul et al., 2023; Alene et., al, 2022). Fibers act as internal reinforcements within the earth mixture, helping to distribute loads more evenly. This reduces the concentration of local stresses that can cause cracks. Cohesion and the uniformity of the block are also improved. Additionally, during the drying process of the CEB, the internal network of the block is strengthened by the fibers, which minimize the tensile forces due to drying shrinkage.

Using starch to stabilize the earth results in a slight decrease in compressive strength from 1 MPa to 0.87 MPa under the curing conditions described in Section 3.2. This suggests that the curing conditions or the use of starch need to be reviewed, as other studies report improved CEB strength with starch incorporation (Tourtelot et al., 2023; Alhaik et al., 2018; Elah et al., 2014).

The addition of fibers to starch-stabilized earth still provides reinforcement to the block's structure. In fact, fibers enhance the physical structure, while starch improves the bonding and uniformity of the mixture. The strengths increase from 1 MPa for the non-stabilized blocks to 3.21 MPa, representing a threefold improvement. However, this value is somewhat lower than that achieved with fiber reinforcement alone.

All these values remain below the reference determined with 5% cement stabilization. These CEBs develop a compressive strength of 7.58 MPa with a density of 1,993 kg/m^3.

These findings are illustrated in Figure 4.



(a) (b)

Fig.4. Compressive strength and density of BTC: (a) Band diagram, (b) Trend curve

4. Conclusions

The study evaluated the impact of starch stabilization and fiber reinforcement on the mechanical strength of Compressed Earth Blocks (CEBs). Our findings reveal that while starch as a natural binder led to a moderate reduction in internal cohesion—decreasing strength by 13%—the inclusion of fibers significantly bolstered block resistance. Specifically, fibers alone enhanced compression resistance by a factor of 3.57, whereas their combination with starch yielded a slight decrease to a factor of 3.21.

Cement stabilization, despite providing the highest mechanical strength with a factor of 7, comes with a substantial environmental cost due to high production energy and carbon footprint.

Conversely, natural fibers and starch offer sustainable alternatives, demonstrating effective improvements in CEB performance while minimizing environmental impact. This underscores the potential of these eco-friendly materials in advancing construction practices that align with both structural and environmental goals.

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