

# Effect of Curing Cycles on the Characterization of Laterite Soils Stabilized with Cement and Natural Pozzolan

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## Abstract

**Background:** To promote the use of local materials, reduce construction costs and energy consumption, and improve environmental conditions, many researchers are focusing on partially or fully replacing Portland cement with pozzolanic binders. Compressed earth blocks can be stabilized by adding small amounts of cement and natural Pozzolan to enhance some of their properties. The aim of this study is to analyze the influence of curing conditions (steam curing, oven curing, and room temperature curing) and the addition of natural Pozzolan on the mechanical properties of compressed earth blocks. **Materials and Methods:** For this purpose, laterite soil from Banengo was used, with 8% cement (by weight of the dry mix) from the CIMAF brand, type CEM II/B-M 42.5R, which has a setting time of 1 hour at 20°C. Four levels of natural pozzolan 8%, 16%, 24%, and 32% were added, sourced from the Foubot quarry. The sample with 0% pozzolan is used as the control group. The blocks were then subjected to three types of curing: steam and oven curing at 40°C, 60°C, and 80°C for 24 hours, and room temperature curing at 22°C ± 2°C for 28 days. **Results and Discussion:** Steam curing at 80°C for 24 hours produced the best results in terms of mechanical strength and durability, compared to the other methods. Oven curing also gave good results, while room temperature curing led to lower performance. This is due to better hydration and crystallization of the reaction products at higher temperatures, which speeds up the pozzolanic reaction. In addition, a pozzolan content of 32% gave the best mechanical strength for cement-stabilized earth blocks cured with steam. **Conclusion:** Increasing the amount of pozzolan significantly improves the mechanical strength and durability of compressed earth blocks.

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## Keywords

Compressed Earth Block, Natural Pozzolan, Strength, Durability, Curing

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## 1. Introduction

Earth, in forms like clay, silt, or sand, is one of the oldest building materials used by humans. It requires little energy to process and produces very low CO<sub>2</sub> emissions [1]. It is also widely available in most parts of the world. Because of this, earth construction has been one of the most common types of housing for thousands of years, offering sustainable, eco-friendly, and aesthetic solutions. However, the benefits of earth as a building material have been largely forgotten with the rise of modern materials like concrete and steel. Today, due to environmental and economic challenges, there is renewed interest in building with earth. Current research mainly focuses on improving its physical and mechanical properties, especially its resistance to water which remains a major weakness of earthen structures. Compressed Earth Blocks (CEBs) are a modern version of traditional adobe blocks [2]. They are small rectangular masonry units made by compressing moist earth in a mold, then removing it immediately. When stabilized with cement, these blocks can withstand high temperatures [3]. This study explores the use of natural Pozzolan in cement-stabilized compressed earth blocks, an area that is still not well studied. The goal is to improve their mechanical strength and durability. Specifically, this work examines how curing conditions affect the mechanical properties of cement-stabilized CEBs [4], and how adding Pozzolan from Foubot (West Cameroon) influences their physical and mechanical behavior.

## 2. Materials and Methods

The preparation of a construction material requires a raw material and a well-defined production method. The quality of the material depends on how it is made and on the natural properties of the raw materials used.

### 2.1. Materials

For this study, the raw materials used are: Portland cement (which helps bind the soil particles together), pozzolan (which reacts chemically with the cement to form additional binding compounds), laterite (which forms the framework of the bricks), and water (which ensures cement hydration and creates cohesion between the dry particles). The soil samples for our experiments were taken from the West region of Cameroon, in the Bafoussam 1 subdivision, specifically in the Banengo neighborhood (Pont Voltaire), at a depth of 1.00 meter below the surface. The natural Pozzolan, of volcanic origin, comes from a quarry located in the West region, specifically in Foubot. The cement used is a Portland type (CPJ 42.5) produced by the CIMAF company, with a setting time of 2 hours at 22°C and a specific weight of 3.10, and the water used for hydration was taken from the CAM-

WATER potable water distribution network.

## 2.2. Methods

After collecting the soil and natural Pozzolan samples from the site, they were air-dried for 4 days and then sieved using a 5 mm mesh. These different materials were identified according to French standards and analyzed at the TWS laboratory in Cameroon. Physical tests were carried out, including visual inspection (to evaluate the number of fine particles), smell test (to detect organic matter), Indentation test (to feel the soil texture), touch test (to assess texture), and washing test (to estimate plasticity). Other tests included natural moisture content, specific and bulk density, particle size distribution (percentages of sand, gravel, and clay), and Atterberg limits. Mechanical tests such as the Proctor test (to determine the optimal moisture content and maximum dry density) were also performed to determine their characteristics.

To improve the mechanical properties of compressed earth bricks, we chose two types of treatment: one using 8% cement, and the other a mixed treatment (cement + Pozzolan). **Table 1** below shows the quantity of materials used for each batch of blocks and the sample (M1) with 0% pozzolan is used as the control group. The Proctor test helped us determine the optimal moisture content that corresponds to the maximum dry density for each type of compressed earth brick. Before mixing, we made sure the materials were completely dry. Then, we performed dry mixing of the soil and Pozzolan for 2 minutes, followed by the addition of binders and continued mixing for 1 minute. Water was then added, and the entire mixture was mixed again for 2 minutes. The material was placed into a traditional mold of size  $4 \times 4 \times 16$  cm and compacted immediately after mixing using a manual press.

**Table 1.** Composition of the CEBs mixtures.

Samples	M1	M2	M3	M4	M5
Lateritic soil (%)	92	84	76	68	60
Cement (%)	8	8	8	8	8
Natural Pozzolan (%)	0	8	16	24	32

These samples were subjected to three curing methods for the compressed earth bricks (CEBs). The first method used steam curing at 40 °C, 60 °C, and 80 °C for 24 hours. The second method used oven drying at 40 °C, 60 °C, and 80 °C for 24 hours. The third method used ambient temperature, where the bricks were covered with plastic sheeting for 28 days. After curing, the bricks were tested for mechanical properties (compression and flexural strength) and durability (water absorption and porosity).

## 3. Results

### 3.1. Physical Parameters

The results of tests on the laterite used, based on French AFNOR standards, are

shown in **Table 2**.

**Table 2.** Physical characteristics of Banengo laterite.

Density	OPM		Natural moisture content (%)	AASHTO classification
Specific (g/cm <sup>3</sup> )	Dry ( $\gamma_s$ ) g/cm <sup>3</sup>	moisture content (%)		
2.00	1.853	13.20	3.71	A-2-7 (0)

In summary, field analysis showed that the soil did not contain organic matter. The touch test revealed that when the soil sample is crumbled, it feels rough, which means the soil has a high sand content. The hand-washing test indicated that the soil was not sticky, and the indentation test showed that it made a gritty sound, suggesting low clay content.

The Atterberg limits showed a liquid limit (LL) of 57.40% at 25 blows and a plastic limit (PL) of 33.33%. These values are lower than those obtained by Djuickouo [5] in Dschang (LL = 63%, PL = 43%). The plasticity index (PI) was 24.07%, which is higher than the values reported by Djuickouo [5], and Dongmo [6], 20% and 21.52% respectively. This means our laterite is a plastic and moderately clayey soil.

The particle size distribution showed that the soil is well-graded, with 63.63% gravel, 33.47% coarse sand, and 2.90% fine sand. Therefore, the Banengo laterite can be classified as gravelly lateritic soil. It falls within the grain size range suitable for earthen construction, according to the Cameroonian CEBs standard (NC 102-114, 2002-2006). This material is suitable for making compressed earth bricks, as described in the ORAN standard (1996) and by Mamba [7].

Regarding the pozzolan, the results of tests performed according to the French AFNOR 1984 standards are shown in **Table 3**.

**Table 3.** Physical characteristics of the pozzolan used.

Density		Natural moisture content (%)	Gravel equivalent - Visual	
Specific ( $\gamma_s$ ) g/cm <sup>3</sup>	Bulk ( $\ell_0$ ) g/cm <sup>3</sup>		visual ESV (%)	Piston ES (%)
2.34	1.50	9.90	79.25	80.60

The particle size distribution showed that the Pozzolan is well-graded, with 15.32% gravel and 84.68% sand.

### 3.2. Compressive Strength of the Different Samples

**Figure 1** shows steam curing, oven curing, and ambient temperature curing, illustrates the changes in compressive strength for the different samples. From these figures, we observe that compressive strength increases as the percentage of natural pozzolan increases, and also with higher curing temperatures. This result con-

firm the findings on the physical and mechanical behavior of compressed earth blocks [8] [9].

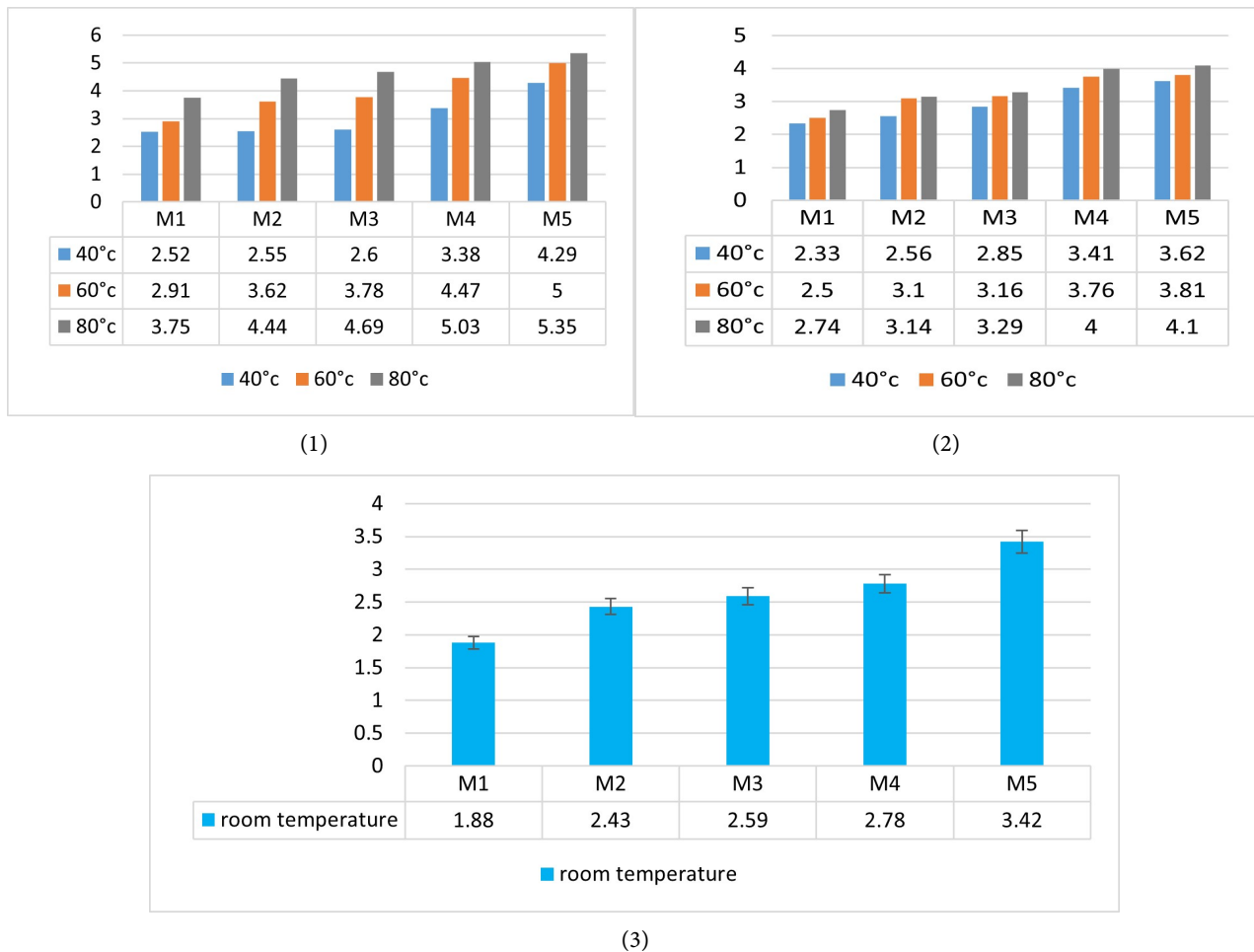


Figure 1. Compressive strength with steam curing (1), oven curing (2), and ambient temperature curing (3).

### 3.3. Flexural Strength of the Different Prototypes

Figure 2, which shows steam curing, oven curing, and ambient temperature curing, illustrates the variations in flexural strength for the different samples. From these figures, we observe that flexural strength increases as the amount of natural pozzolan increases, and also with higher curing temperatures. This result supports previous findings on the physical and mechanical behavior of compressed earth blocks, as reported by Milogo *et al.* (2011) and Ouedraogo *et al.* (2017).

### 3.4. Influence of Curing Methods on Mechanical Strength

The results show that steam curing significantly increases the compressive strength of the bricks compared to bricks cured at ambient temperature for 28 days or in the oven. However, the mechanical strength of CEBs cured with steam for just 24 hours is close to the strength of CEBs cured at ambient temperature for 18 months. This can be explained by the steam curing process, which accelerates

cement hydration and the pozzolanic reaction between the cement and the soil [3].

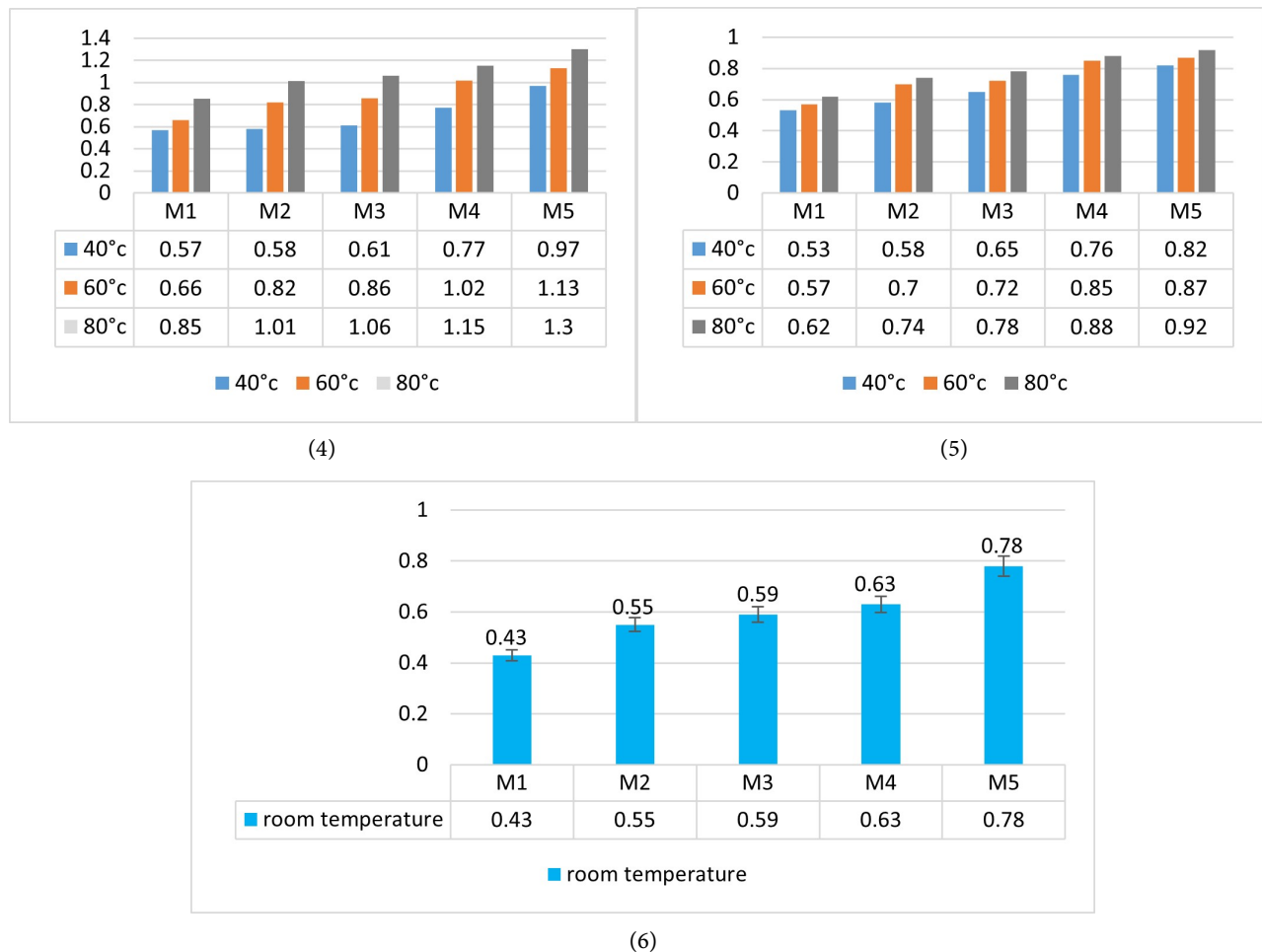


Figure 2. Flexural strength with steam curing (4), oven curing (5), and ambient temperature curing (6).

### 3.5. Water Absorption and Porosity

In this case, water absorption decreases with the addition of pozzolan. The best result is obtained with 32% natural pozzolan. The samples showed an absorption rate below 15%, which meets the limit recommended by the Cameroonian standard (NC 102-114, 2002-2006).

## 4. Discussion

### • Regarding Mechanical Behavior

The addition of natural pozzolan significantly improves both the compressive and flexural strength of the bricks, compared to sample 1, which contains no pozzolan.

- **Compressive strength** increased from 3.75 MPa for sample 1 to 5.35 MPa for sample 5 under steam curing at 80°C.
- **Flexural strength** increased from 0.85 MPa for sample 1 to 1.30 MPa for

sample 5 under steam curing at 80°C.

Sample 5, with 32% pozzolan, showed the best mechanical performance. Steam curing at 80°C gave better results than oven curing or ambient curing. Thus, increasing the pozzolan content significantly improves the performance of the bricks regardless of the curing method, by densifying the matrix and enhancing the pozzolanic reactions.

- **Regarding Water Behavior**

Water absorption decreases as the Pozzolan content increases. Sample 5, with 32% pozzolan, had the lowest water absorption. Curing at 80°C (either steam or oven) improves water-related properties compared to ambient temperature curing.

- **Regarding the Effect of Curing Method**

- **Steam curing:** best performance, with significant improvement in both mechanical strength and durability.
- **Oven curing:** Slightly lower performance than steam curing, but still better than ambient curing (intermediate results).
- **Ambient curing:** Lowest performance overall.

Raising the curing temperature from 40°C to 80°C also improved performance, regardless of the curing method. High-temperature steam curing (80°C) proves to be the most effective method for fully enhancing the potential of these stabilized earth bricks. This can be explained that heat increases the dissolution rate of silica and alumina from the pozzolan, which then react with calcium hydroxide from cement hydration.

## 5. Conclusions

This study highlighted the positive influence of curing cycles and the addition of natural pozzolan on the performance of soil cement pozzolan mixtures. Based on the experimental results, the following points can be made:

- Steam curing at 80°C for 24 hours is sufficient to reach almost the maximum strength (dry tensile strength and compressive strength) for cement-stabilized compressed earth blocks (CEB).
- The pozzolanic reaction occurs very slowly at ambient temperature, meaning that several months are needed before its effects become noticeable.
- This study also showed that at a cement content of 8%, the disintegration of the bricks in water is due to poor or even absent cohesion between the particles in the brick.
- These results demonstrate that adding natural pozzolan and applying optimal curing cycles can significantly improve both the mechanical and water-related performance of stabilized earth bricks, with sample 5 (containing 32% pozzolan) being the most effective formulation.

However, it is crucial to consider potential trade-offs, such as increased energy and equipment costs for steam curing, versus observed performance improvements. A balanced assessment of costs and benefits is necessary to ensure the eco-

conomic viability of these techniques in practical applications.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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