THERMAL CONDUCTIVITY OF COMPRESSED EARTH BLOCKS PRODUCED WITH RECYCLED CEMENT

M. Glória Gomes¹*, J. Alexandre Bogas¹, S. Real¹, R. Cruz¹

¹ CERIS, Department of Civil Engineering, Architecture and Georesources, Instituto Superior Técnico, Universidade de Lisboa, PORTUGAL
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1. INTRODUCTION

PROJECT Eco+RCEB - ECO-EFFICIENT RECYCLED CEMENT COMPRESSED EARTH BLOCKS

This work is financed by the Portuguese Foundation for Science and Technology (FCT), under the project Eco+RCEB - Eco-efficient recycled cement compressed earth blocks (PTDC/ECI-CON/0704/2021)

https://cdwvalue.eu/project-ecorceb
OUTLINE

1. Introduction
2. Materials and methods
3. Experimental results and discussion
4. Conclusions
1. INTRODUCTION

Earth building material

has been exploited in construction for centuries due to its:

• production simplicity and high material abundance
• low embodied energy and carbon footprint
• high sound insulation
• high thermal inertia and higroscopicity and low thermal conductivity

Energy efficient envelope that can ensure a good hygrothermal comfort of occupants with low energy demand

Great Mosque of Djenné (built in 1907, Mali, Africa)

https://www.re-thinkingthefuture.com/rtf-fresh-perspectives/a1627-10-stunning-examples-of-earth-architecture-around-the-world
1. INTRODUCTION

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fell into disuse, especially after the 19th century, with the:

• development of new construction techniques
• use of alternative building materials
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A renewed interest in earth as a building material emerged with the recent:
• concerns of more sustainable construction materials
• the emergence of new construction techniques, namely mechanical and chemical stabilisation, to improve their performance
1. INTRODUCTION

Earth building material


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1. INTRODUCTION

Of the various earth construction techniques, such as ancient rammed earth and molded adobes, **compressed earth blocks (CEB)** are expected to be most easily accepted by modern society since:

- the improved mechanical properties (mech. stabilization)
- greater manufacturing control

To overcome the CEB water susceptibility and poor durability, cement can be used in CEB production (chemical stabilization) as it improves:

- volume stability
- strength
- durability

A renewed interest in earth as a building material emerged with the recent:

- concerns of more sustainable construction materials
- the emergence of new construction techniques, namely **mechanical and chemical stabilisation**, to improve their performance (structural strength, water resistance and dimensional stability)
1. INTRODUCTION

BUT cement manufacture is high carbon-polluting

need to adopt more sustainable practices in the concrete sector => low-carbon thermoactivated recycled cement (RC) produced from recycled construction and demolition waste materials

GOAL This study aims to:
• analyse the influence of the incorporation of RC in the thermal conductivity and hygroscopic sorption properties of compressed earth blocks (CEB)
• compare with reference CEB not stabilised or produced with equal Portland cement content

WHAT HAPPEN TO THE HYGROTHERMAL PERFORMANCE OF CEB?
2. MATERIALS AND METHODS

7 different CEB compositions:
• 2 with 5% and 4 with 10% of stabiliser (Portland cement – PC and recycled cement – RC)
• 1 reference unstabilised CEB (UCEB), for comparison purposes

<table>
<thead>
<tr>
<th>Designation</th>
<th>Soil(^a) (%)</th>
<th>PC(^b) (%)</th>
<th>RC(^b) (%)</th>
<th>Water(^b) (%)</th>
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<tbody>
<tr>
<td>PC10</td>
<td>90</td>
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<tr>
<td>UCEB</td>
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<td>-</td>
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<td>14.4</td>
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\(^a\) Soil with 4% humidity; \(^b\) By weight of solids (soil+stabiliser); \(^c\) Total w/b, including water absorbed by soil

5-10% stabiliser with 0, 20, 50, 100% RC

reference unstabilised CEB
2. MATERIALS AND METHODS

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<th>Designation</th>
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The soil is composed of 20.1% gravel, 48.4% sand and 31.5% silt/clay
- organic matter content <1%
- density 2.7 g/cm³
- optimum moisture content 16%
- liquid limit 30%
- plasticity limit 22%
- plasticity index 8%
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1 - Production of the cement specimens; 2 - Large jaw crusher (< 7 cm); 3 - Small jaw crusher (< 3 cm); 4 - Roller mill (< 1 cm); 5 - Ball mill (< 250 µm); 6 - Sieving; 7 - Thermoactivation at 650 ºC
2. MATERIALS AND METHODS

CEB PRODUCTION (220x105x60 mm) | Manual press of about 3.5MPa

- CEB were subjected to 7 days of wet curing whereas UCEB underwent dry curing (7 days covered with a plastic film).
- After this period, the CEB were air cured under laboratory conditions up to testing age.
2. MATERIALS AND METHODS

Experimental campaign

Thermophysical and hygroscopic sorption properties

- Thermal conductivity ($\lambda$)
- Density ($\rho$)
- Moisture content ($\psi$)
- Sorption and desorption curves

7 different CEB compositions:
- 6 stabilised with PC and RC (PC10; RC10; PC5; RC5; RC2PC8; RC5PC5)
- 1 unstabilised (UCEB)

Dry state

Higroscopic range

Over-higroscopic range
2. MATERIALS AND METHODS

Experimental campaign

Thermophysical and hygroscopic sorption properties

7 different CEB compositions: 6 stabilised with PC and RC (PC10; RC10; PC5; RC5; RC2PC8; RC5PC5) and 1 unstabilised (UCEB)

THERMAL TESTS

- Surface probe

- Thermal conductivity ($\lambda$)
- Density ($\rho$)
- Moisture content ($\psi$)
- Sorption and desorption curves
2. MATERIALS AND METHODS

Experimental campaign

Thermophysical and hygroscopic sorption properties

7 different CEB compositions:
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- Thermal conductivity (\(\lambda\))
- Density (\(\rho\))
- Moisture content (\(\psi\))
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DENSITY AND MOISTURE CONTENT

- High precision weighting scale
- Micrometer
- The density was determined by the geometric method (EN 1015-10)
- Moisture content volume by volume
2. MATERIALS AND METHODS

**Experimental campaign**

Thermophysical and hygroscopic sorption properties

7 different CEB compositions: **6 stabilised** with PC and RC (PC10; RC10; PC5; RC5; RC2PC8; RC5PC5) and **1 unstabilised** (UCEB)

**SORPTION AND DESORPTION CURVES**

- **CLIMATIC CHAMBER METHOD** ([EN ISO 12571](#))
- 35%, 65%, 80% and 95% relative humidity (RH), at constant temperature (T=23 ± 0.5°C)
- 0% RH - oven drying the samples at 60°C±5°C until constant mass
3. RESULTS AND DISCUSSION

- Thermal conductivity tended to increase with the moisture content
- Thermal conductivity of the CEB in the saturated state was more than twice as high as those in the dry state, with this difference being maximized in the blocks with RC incorporation
- The effect of the moisture content was more relevant to the thermal conductivity than other parameters, such as the type and amount of stabiliser

Unstabilised CEB disintegrated after a few hours submerged in water.

Not tested in the saturated state
3. RESULTS AND DISCUSSION

- Oven-dried CEB showed 12% to 20% lower thermal conductivity than air-curing CEB (water eliminated during air-curing)
- The incorporation of RC in CEB decreases the thermal conductivity up to 30% (higher porosity associated to the CEB with RC, produced with a higher amount of water to account for the higher water demand and porosity of this stabiliser)
3. RESULTS AND DISCUSSION

○ A high correlation between the thermal conductivity in the dry state with the total porosity of CEB
3. RESULTS AND DISCUSSION

Thermal conductivity of CEBs is also directly related to their density.

- Present work
- Silva (2015)
- Alengram et al. (2013)
- Sengul et al. (2011)
- Lo-Shu et al. (1980)
- Bogas and Cunha (2015)
- Valore (1980)
3. RESULTS AND DISCUSSION

- Stabilised CEBs present a higher adsorption of water vapour compared to the UCEB
- There is sorption hysteresis, with desorption giving higher equilibrium moisture contents than sorption at equal ambient climate conditions
3. RESULTS AND DISCUSSION

- The higher moisture content and relative humidity, the greater the thermal conductivity of CEB, showing the importance of assessing the moisture content in service conditions.
3. RESULTS AND DISCUSSION

- Thermal conductivity of stabilised CEBs with RC is lower than with PC but tend to be more affected by the moisture content, because air in a higher volume of voids is replaced by the more conductive water.
- The more significant increase of thermal conductivity occurs for relative humidity higher than 80% (micro capillary pores filled with water).
7. CONCLUSIONS

- An experimental campaign was performed to assess the thermophysical and hygroscopic sorption properties of 7 different compressed earth blocks (6 stabilised with PC and RC and 1 unstabilised), for dry, hygroscopic and over-hygroscopic ranges.
- Thermal conductivity, density, moisture content and sorption and desorption curves were determined.
- Thermal conductivity of CEBs increases with both density and moisture content.
- Stabilised CEBs present, in general, a higher adsorption of water vapour compared to the UCEB.
- The CEB stabilised with RC displayed lower thermal conductivities (up to 30%) than UCEB or CEB stabilised with PC but is more affected by the moisture content (higher porosity).
- RC is a more eco-efficient alternative to PC that can be successfully incorporated in CEBs showing additional benefits in the thermal performance of the CEBs.
THANK YOU FOR YOUR ATTENTION

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