Eco+RCEB

Eco-efficient recycled cement compressed earth blocks

FCT Project

PTDC/ECI-CON/0704/2021

Report Eco+Rceb/R2

Characterisation of materials: cementitious stabilisers

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Preface

Although it is estimated that more than 30% of the world's population still inhabit earthen dwellings, in the last two centuries earth has fallen into disuse, due to the emergence of new building materials and construction techniques. However, in line with the increasing demand of more sustainable and eco-friendly building materials, earth construction has regained interest. The low environmental impact and embodied energy, the high availability of raw material, the recyclability, the high hygrothermal comfort, the improved indoor environmental quality, with nearly zero hazardous emissions, and the advances in new construction methods and in the materials science, are some reasons that contributed to the resurgence of earth construction.

A promising approach to earth building materials is the compressed stabilised earth blocks (CSEB), increasing the processing speed and showing improved mechanical strength and durability when stabilised with cementitious materials, such as ordinary Portland cement or hydraulic lime. However, despite its adequate behaviour in real exposure conditions, this type of CSEB fails to address the sustainability issue, since it requires a considerable amount of non-eco-friendly stabilisers.

Alternative more sustainable natural stabilisers have been explored by various investigators, but they are still far from being technically viable and from providing comparable mechanical and durability performance as cementitious materials.

In this context, the low-carbon thermoactivated recycled cement is expected to be a very promising alternative for CSEB stabilisation, potentially providing adequate binding properties with reduced environmental impact. Comparing to conventional cement stabilisers, the new eco-efficient binder contributes to a lower consumption of natural resources and, potentially, over 60% reduction of CO_2 emissions, while adequately repurposing construction and demolition waste.

Therefore, the main objective of this project is the innovative production and characterisation of more eco-friendly CSEB, by using low embodied energy recycled cement from concrete waste as a more sustainable stabiliser. The idea is to also explore the incorporation of construction and demolition waste as partial earth replacement, further increasing the CSEB sustainability.

The new CSEB will be characterised in terms of their main physical, mechanical, thermal and durability properties by means of laboratory tests, as well as in-situ tests involving the long term exposure of various CSEB walls to different natural environments. In addition, the project also aims the development and characterisation of new more eco-efficient masonry earth mortars for CSEB joints, using recycled cement.

For the accomplishment of these objectives, a comprehensive experimental program was defined involving the following six main tasks: production of compressed earth blocks stabilised with recycled cement; masonry earth mortar characterisation and CSEB wall production; physical, mechanical and microstructural characterisation of CSEB; thermal performance of CSEB; durability of CSEB; life-cycle cost and life-cycle assessment of CSEB.

1. Introduction

The present study is part of FCT research project, PTDC/ECI-CON/0704/2021, which consists on the production and characterisation of eco-efficient compressed stabilised earth blocks, contributing for the resurging interest and confidence in using earth materials, towards a more eco-friendly and sustainable construction practice.

This report presents the production and characterisation of the stabilisers to be used in the production of the compressed stabilised earth blocks (CSEB) for Phase 1, namely Portland cement and thermoactivated recycled cement (RC).

2. Characterisation of stabilisers

2.1 Portland cements

In this study, ordinary Portland cement (OPC) (CEM I 42.5 R) was used as a binder to produce the source paste and concrete, as well as a stabiliser to produce reference CSEB. Moreover, Portland limestone cement (PLC) (CEM II/B-L 32.5N) was also used as a stabiliser. These cements were provided by SECIL. Table 1 presents the main properties of this cement.

Table 1 – Properties of ordinary Portland cement and Portland limestone cement

Parameter		Standard	OPC (CEM I 42.5R)	PLC (CEM II/B-L 32.5N)
Density (g/cm^3)		LNEC E 64 [1]	3.02	-
Compressive strength of reference mortar at 28 days (MPa)		EN 196-1 [2]	53.3	≥32.5 and ≤52.5 [a)]
$SiO_2+Al_2O_3+Fe_2O_3$ (%)		EN 196-2 [3]	38.79+5.09+2.87	-
CaO+MgO (%)		EN 196-2 [3]	60.48+1.77	-
Free CaO (%)		EN 451-1 [4]	1.02	18.5
Loss on ignition (950°C) (%)			4.04	15.8
Normal consistency (w/b)		EN 196-3 [5]	0.295	-
Setting time (min)	beginning	EN 196-3 [5]	190	≥75 [a)]
	end		310	-

[a)]According to supplier's product specifications

2.2 Thermoactivated recycled cement

For the production of thermoactivated recycled cement from paste waste (RCP) and concrete waste (RCC), source cement paste and concrete were produced, which later underwent particle size reduction and thermal activation processes, as discussed in detail below.

2.2.1 Production of source paste and concrete

The source cement paste was mixed in a cylindrical container with 50 L capacity and a mixing drill. First, 50% of the mixing water was placed in the container. Afterwards, cement was slowly added and mixed for 4 minutes. Finally, the remaining water was gradually added to the mixture for another 4 minutes (Figure 1).

The source concrete was produced in a vertical shaft mixer with bottom discharge. The coarse limestone aggregates and siliceous sand were placed in the mixer with 50 % of the total water. After mixing for 2 minutes, the mixture was left to rest for 1 minute before adding the cement and the rest of the water. The total mixing time was about 7 minutes (Figure 2).

Figure 1 – Source cement paste production

Figure 2 – Source concrete production

The source paste and concrete were moulded into 0.15x0.15x0.15m cubes (Figure 3). After demoulding, the source materials were left in natural environmental conditions for at least 3 months (Figure 4).

Table 2 presents the composition of the source materials, as well as their slump, fresh density and compressive strength at 28 days, determined according to EN 12350-2 [6] (Figure 5), EN 12350-6 [7] (Figure 6) and EN 12390-3 [8] (Figure 7), respectively. The source paste was produced with the same composition of concrete waste, in order to get the same type of cementitious fraction.

Figure 3 - Source cement paste cubes

Figure 4 – Specimens kept in atmospheric conditions

Table 2 – Composition, fresh density and compressive strength of the source materials

Designation	Type of aggregate	w/c	M_{binder} (kg/m³)	$V_{coarse\ aggregate}$ (L/m³)	$V_{sand\ aggregate}$ (L/m³)	V_{water} (L/m³)	Slump (mm)	Fresh density (kg/m³)	Compressive strength at 28 days (MPa)
Source concrete	Limestone and siliceous sand	0.55	360	406	260	198	130	2340	43.2
Source paste	-	0.55	1032	-	-	568	-	1770	33.4

Figure 5 – Slump test setup

Figure 6 – Fresh density test setup

Figure 7 – Compressive strength test setup

2.2.2 Source materials processing

After about 3 months in natural environmental conditions, the source materials underwent particle size reduction.

First, the source paste was crushed in two jaw crushers with different jaw openings (2cm (Figure 8) and 1cm (Figure 9)) and then milled in a roller mill (Figure 10).

Then, the source paste particles were oven-dried at 105°C, in order to minimise the particle agglomeration and maximise the efficiency of the following processing step, which was further particle size reduction in a ball mill (Figure 11).

Figure 8 – Jaw crusher with a jaw opening of 2cm

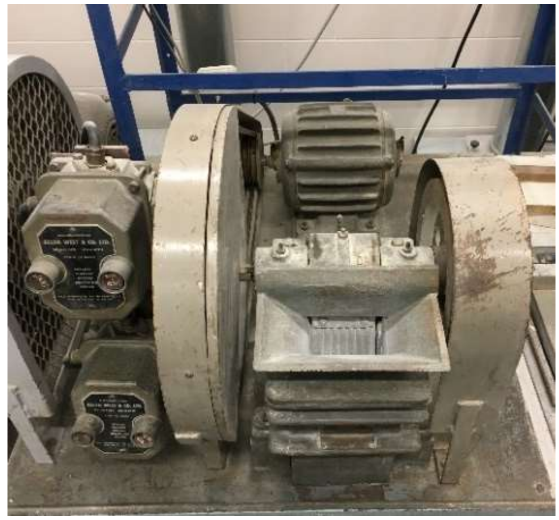

Figure 9 – Jaw crusher with a jaw opening of 1cm

Figure 10 – Roller mill

Figure 11 – Ball mill

After being milled in the roller mill, the source concrete particles were sieved into various granulometric fractions (Figure 12), namely <150 µm; 150- 250 µm; 250-500 µm; >500 µm. Then, the most suitable fractions (150 to 500 µm) were subjected to magnetic separation (Figure 13), through a patented method [9] developed in a previous research work. Afterwards, the separated magnetic fraction, essentially composed of cement particles, was subjected to further particle size reduction in a ball mill.

The processing of the source materials resulted in hydrated cement waste particles under 250 µm.

Figure 12 – Sieving of source concrete particles

Figure 13 – Magnetic separation setup

2.2.3 Thermal activation

After the particle size reduction, the source paste particles and the separated cement particles from the source concrete underwent thermal activation in a rotary tube furnace from *Thermolab Scientific Equipments* (Figure 14).

The thermal treatment was carried out up to a maximum temperature of 650°C, with a residence period of 3 hours, and a plateau of 1 hour at 150°C during the initial heating ramp at 10°C/min (Figure 15).

After the thermal activation process, two eco-efficient binders were obtained, RCP and RCC.

Figure 14 – Rotary tube furnace

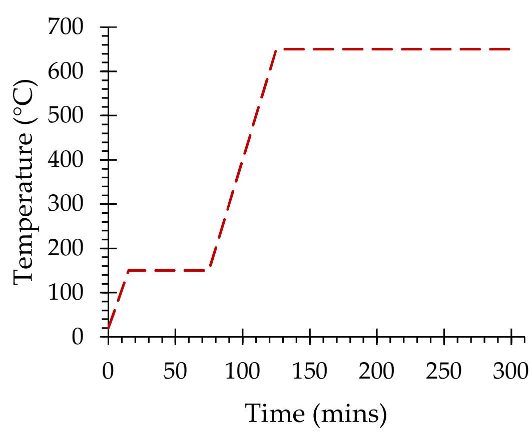

Figure 15 – Thermal treatment procedure

2.2.4 Characterisation of thermoactivated recycled cements

Table 3 presents the main properties of the produced RCP and RCC. Overall, the density of RC was slightly lower than that of OPC (Table 1), essentially due to their porous nature. Moreover, the water requirement for normal consistency was significantly higher in RC than in OPC, not only owed to their greater porosity, but also to their higher surface area and high free CaO content (Table 3). Furthermore, the setting time of RC was also higher than that of OPC, which may be explained by the longer dormancy period of RC hydration, in which the main compound, α'_H-C_2S, only starts reacting with relevance after 1 day [10]. The presence of 29% inert aggregates in RCC explains the lower water requirement and higher setting time than RCP.

Table 3 – Properties of the thermoactivated recycled cements

Parameter		Standard	RCP	RCC
Density (g/cm^3)		-	3.005[a)]	2.964[a)]
BET specific surface (cm^2/g)			156853	78673
Loss on ignition (950°C) (%)			6.35	22.24
SiO_2+Al_2O_3+Fe_2O_3 (%)		EN 196-2 [3]	18.78+5.24+3.16	19.42+4.31+2.40
CaO+MgO (%)		EN 196-2 [3]	60.77+1.93	47.00+1.29
Free CaO (%)		EN 451-1 [4]	13.19	-
Normal consistency (w/b)		EN 196-3 [5]	0.76	0.54
Setting time (min)	beginning	EN 196-3 [5]	290	>720
	end		460	<1440

a) Helium pycnometry

Due to its high water requirement, it was not possible to produce a RC mortar with the same composition as that of the reference OPC mortar (Table 1). Nonetheless, a mortar with RCP and a water/binder ratio (w/b) of 0.67 could be produced, resorting to the addition of 3.5% of superplasticiser. This mortar achieved a compressive strength at 28 days of 19.9 MPa. For comparison purposes, an OPC mortar with a w/b of 0.67 was also produced, having displayed a compressive strength at 28 days of 37 MPa, which is almost twice that of the RCP mortar of similar composition. In spite of the results this demonstrates the high rehydration capacity of RC and its potential to be used as a stabiliser.

3. Conclusions

This report showed the production and characterisation of the stabilisers to be used in the production of the compressed stabilised earth blocks for Phase 1.

For the production of thermoactivated recycled cements (RC), source paste and source concrete were produced with Ordinary Portland cement (OPC) and a water/binder ratio of 0.55, having displayed compressive strengths at 28 days of 33.4 and 43.2 MPa, respectively. The source materials were subjected to a series of particle size reduction and separation processes, and then, subjected to thermal treatment, having resulted in RC from paste waste (RCP) and from concrete waste (RCC). Besides rehydration capacity, these RC displayed higher CaO content, surface area, water demand and setting time than OPC.

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