Physical and Mechanical strength characterization of compressed earth blocks produced with recycled cement

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Earth has the longest track record as a building material, being used since most remoted ancient times (Hall and Swaney 2012, Cid-Falceto et al. 2012). However, although earth dwellings still house over 30% of the world's population (Van Damme and Hoben 2018), in the last two centuries earth construction has given place to other emerging materials of greater mechanical and durability performance (Riza et al. 2010), such as steel and concrete. Indeed, earth cannot be technically competitive with these materials, especially in tall buildings, special structures and uncoated elements exposed in humid environment.

However, the rising priorities of sustainable development and environmental protection, have sparked interest in more eco-friendly materials. In this case, the low environmental impact and embodied energy, high availability of raw material (close to the construction site), low cost and recyclability, as well as other advantageous features, such as improved hygrothermal comfort (Hall and Swaney 2012, Van Damme and Hoben 2018), have contributed to the resurgence of earth as a viable building material (Nagaraj et al. 2014), at least for small buildings. Various examples of modern earth construction have been reported in the last few years, from North America to Europe, Asia and Australia (Hall and Swaney 2012).

Compressed earth blocks (CEB) is a technique that allows to improve earth performance, due to the action of high-pressure compaction, increasing the cohesion between particles and their bear strength (Cid-Falceto et al. 2012, González-López et al. 2018). In addition, to overcome the high variability and low integrity of earth, especially in humid environment, chemical stabilization is absolutely necessary (Mansour et al. 2016). In this regard, ordinary Portland cement (OPC) is the most efficient stabilizer, ensuring adequate mechanical and durability performance of CEB for an incorporation amount of 5-10% by weight of cement (Reddy 2012). However, the use of up to circa 200 kg/m^3 of OPC significantly increases the embodied energy and environmental impact of CEB, eliminating the green nature of earth construction. In fact, the clinker production is responsible for over 7% of the CO_2 world emissions (Sousa and Bogas 2021).

In this context, alternative low-carbon recycled cement (RC), retrieved from concrete waste, has been explored in Instituto Superior Técnico, University of Lisbon (IST-UL) during the last 4 years. The idea is to recover the binding properties of hydrated cement waste, through its thermoactivation at 600-700ºC (Carriço et al. 2020), and obtaining for the first time a hydraulic binder that is 100% recycled and 100% circular. RC directly contributes to the reduction of CO_2 emissions, the saving of natural resources and the effective reuse of construction and demolition waste (C&DW). Moreover, it has been demonstrated the high rehydration capacity of RC and its comparable performance to OPC when incorporated in cement-based materials, namely in mortars and concrete (Carriço et al. 2020b, Bogas et al. 2020, Carriço et al. 2021).

Therefore, this study explores, for the first time, the use of RC as a more eco-efficient solution for CEB stabilization. In this case, CEB produced with different contents (5%, 10%) and types of stabilizer (100% OPC, 100% RC, and blended binders with partial replacement of OPC with 20% or 50% RC) were characterized in terms of their main physical and mechanical properties, namely density, compressive strength, splitting tensile strength, flexural strength, ultrasound pulse velocity, modulus of elasticity, pendulum sclerometer, elasticity modulus, shrinkage and thermal conductivity (Figure 1). CEB were characterized considering different curing (air and wet curing) and wetting conditions (dry, lab conditions, saturated). Unstabilized CEB were also considered for comparison purposes, allowing a better assessment of the potential contribution of RC as a stabilizer.

In general, for the analysed properties, although the performance of CEB decreased with the replacement of OPC with RC, the improvement was significant in relation to unstabilized CEB, especially in humid conditions. The lower performance of RC than OPC in stabilizing the CEB was attributed to the development of a lower amount of long-term hydration products and, especially, to the higher initial total porosity of CEB. The greater water demand of RC led to a higher amount of mixing water, increasing the water/binder ratio and the total porosity of CEB, which was up to 13% higher than that of OPC CEB. Therefore, under lab conditions of intermediate humidity, RC CSEB showed 25% less compressive strength and 24% less modulus of elasticity than reference OPC CSEB with equal amount of stabilizer. However, the reduction of compressive strength was less than 15% for up to 50% replacement of OPC with RC. A good correlation was found between compressive strength and other mechanical properties, showing the same trend regarding the influence of the type and amount of stabilizer. Long-term shrinkage was lower in RC CEB of greater porosity and lower stiffness than in OPC CEB, but early shrinkage was similar in both CEB. The thermal conductivity was up to 26% lower in RC CEB due to their higher total porosity than OPC CEB. Under extreme saturation or drying conditions, the compressive strength reduction in RC CEB was 43% and 12%, respectively, underlying the lower stabilization capacity of RC than OPC.

Nevertheless, RC was an efficient stabilizer, leading to a significant improvement of tested properties, compared to unstabilized CEB. Stabilization with 10% RC was able to almost double the mechanical strength of unstabilized blocks, under lab conditions, and to ensure the integrity of CEB under saturation conditions, for a compressive strength over 2 MPa. Unstabilized CEB were highly sensitive to water, degrading fast after saturation.

Figure 1 – Mechanical characterization of CEB (from top left to bottom righ): compressive strength; flexural strength; splitting tensile strength; ultrasound pulse velocity; pendulum sclerometer; elasticity modulus; shrinkage; thermal conductivity.

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