



Evaluating earthen mortars for rendering

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ABSTRACT

As it is now recognized worldwide, the use of earth mortars for plastering and rendering is very important due to eco-efficiency. Rendering mortars have to present durability to rain water. A ready-mixed earth mortar based on natural clayish earth, siliceous sand and cut oat fibers was analyzed. In addition to this, three other mortars with volumetric proportion 1:3 (clayish earth: aggregate) were formulated in laboratory. A coarse and a fine sand were used as aggregate. Oat fibers were added to one of these mortars while oat fibers plus air lime were added to another. Microstructure, mechanical strength, capillary absorption, drying and mineralogical composition were evaluated. It was concluded that the addition of a small amount of air lime causes a decrease of mechanical strength and an increase on capillary absorption. For that reason it does not seem the best technique to increase durability for rendering mortars.

INTRODUCTION

Earthen plastering mortars are becoming recognized as highly eco-efficient (Maddison et al. 2009; Darling et al. 2012, Delinière et al. 2014, Lima & Faria, 2016) due to important environmental but also technical advantages, which justify their increased use. One of the technical advantages is the contribution for indoor hygrothermal equilibrium and for the inhabitants' health. While plasters must contribute to the indoor comfort, renderings have to resist the action of climate. For this reason, it is important to study the durability of earth mortars especially facing water. It may be achieved by surface treatments or different admixtures (Stazi et al., 2016).

Earth-based materials are often stabilized with small amounts of limes or cements with the aim of improving their mechanical resistance and durability (Hall et al. 2009). However, that eventual improvement is still not totally proven and little is known about the influence these stabilizers may have on the properties of the material (Gomes et al. 2012).

The sustainability of earth mortars is well known when compared with other types of mortars, mainly in terms of embodied energy. However the uses of chemical stabilizers contribute to the increase of mortar's embodied energy because of the energy needed to produce the binders in comparison with the clayish earth preparation (Mèlia et al. 2014). Furthermore, this addition changes completely the life cycle of the earth material itself, namely in terms of their possibilities to reuse. It is therefore important to evaluate the advantages and disadvantages of adding binders to earth mortars.

1. MATERIALS AND SAMPLES

A ready-mixed earth mortar (P) from Embarro company (Portugal and Spain) based on natural clayish earth, siliceous sand and cut oat fibers with 1-2 cm long, was produced and samples were prepared and tested. Other three earth-based mortars were produced with a clayish earth from the Algarve region (South of Portugal) and two siliceous sands with different particle size distributions (a coarse sand CS and a fine sand FS), cut oat fibers with 1-2 cm long (F) from Conlino (Germany) and a powder hydrated air lime (CL) classified as CL90 by EN 459-1 (CEN, 2010) from Lusal - Lhoist Group (Portugal). The laboratory formulated mortars were produced with 1:3 volumetric proportions of earth and sand. The fibers and air lime were added when defined. Volumetric compositions are presented in Table 1. The earth was always 25%; the formulated mortars are designated by the volumetric percentages of the sands and eventually 5% of fibers and lime. The volumes of water are also presented.

All mortars were produced in laboratory accordingly to DIN 18947 (DIN, 2013). The dry components were homogenized and the water was added during the first 30 seconds of mechanical mixing at low speed. After additional 30 seconds of mixing the mortar rested for 5 minutes and a last period of 30 seconds mixing completed the mortars' production. Mechanical compaction equipment was used to prepare prismatic samples 40mm x 40mm x 160mm in metallic molds with manual leveling. The prismatic samples were de-molded when hardened and reached equilibrium in controlled environmental conditions at $20 \pm 2^\circ\text{C}$ and $65 \pm 5\%$ relative humidity (RH).

Table 1. Mortars volumetric proportions

Mortars	Earth	Sand CS	Sand FS	Fiber	CL	Water
P		1			-	0.2
CS30_FS45	1	1.2	1.8	-	-	0.2
CS30_FS45+F5	1	1.2	1.8	0.2	-	0.25
CS30_FS45+F5+CL5	1	1.2	1.8	0.2	0.2	0.25

2. TESTING AND EVALUATION

2.1 Dry bulk density and microstructure

The dry bulk density was geometrically determined with the samples according to DIN 18947 (CEN, 2013) and EN 1015-10 (CEN, 1999a), by means of a digital caliper and a 0.001g precision digital balance. The open porosity and the pore size distribution were determined by mercury intrusion porosimetry (MIP), using a Micromeritics Autopore II equipment, applied to a specimen taken from the prismatic samples. The test samples were prepared so as to occupy the greater part of 5cm^3 volume of the penetrometer bulb. Testing began at low pressures ranging from 0.014 MPa to 0.207 MPa, followed by high pressure analysis from 0.276 MPa to 206.843 MPa. Results of bulk density determined geometrically and open porosity measured by MIP are presented in Table2. Incremental mercury porosimetry curves are plotted in Figure 1.

Table 2. Density, porosity, dynamic elasticity modulus, flexural and compressive strength.

Mortar	Bulk density [kg/dm^3]	Porosity [%]	Ed [N/mm^2]	FStr [N/mm^2]	CStr [N/mm^2]
P	1.77	29.9	4331	0.24	0.55
CS30_FS45	1.79	28.6	3933	0.22	0.56
CS30_FS45+F5	1.72	30.7	3838	0.19	0.43
CS30_FS45+F5+CL5	1.43	35.7	1577	0.09	0.22

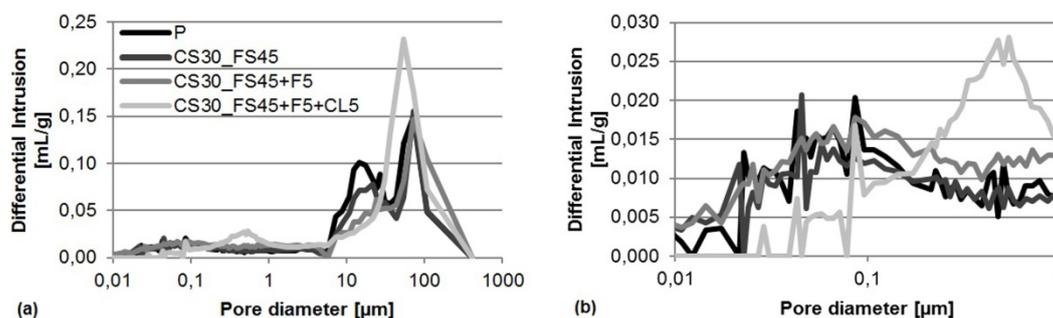


Figure 1. Porosimetry curves: (a) total range and (b) micropores range.

All mortars can be classified in class 1.8 in terms of dry bulk density, according to DIN 18947 (CEN, 2013), except the mortar with addition of air lime, classified in a lower class (1.6). According to Röhlen & Ziegert (2011) earth mortars usually have open porosity values between 20-30%. It is possible to conclude that the analyzed mortars have values within this range, except mortars with addition of fibers and particularly with air lime and fibers which are more porous.

With regard to porosimetry, it is possible to conclude that P, CS30_FS45 and CS30_FS45+F5 mortars present similar behavior between 6 and 108 μm , with higher quantity of peak pores around 72 μm corresponding to 0.15 ml/g. The first two mortars present a bi-modal microstructure as they also have a lower peak around 14 μm (with 0.018 ml/g). Mortars with air lime behave differently, with higher quantity of pores. This mortar present a bi-modal distribution curve with a high percentage of pore interconnection equivalent diameter of approximately 55 μm (with 0.23 ml/g) and with 0.55 μm (with 0.028 ml/g).

2.2 Mechanical strength

The mechanical characteristics were evaluated using three samples. The dynamic modulus of elasticity was determined based on EN 14146 (CEN, 2004), defined for natural stone, using a Zeus Resonance Meter. The flexural and compressive strengths were determined according to DIN 18947 (DIN, 2013) and EN 1015-11 (CEN, 1999b) using a Zwick Rowell Z050 equipment, with load cells of 2kN for flexural and 50 kN for compression. The mechanical characterizations of mortars are presented on Table 2 (average and standard deviation).

The mortars CS30_FS45 and CS30_FS45+F5 presented mechanical characteristics similar to the ready-mixed mortar, while the mortar with air lime showed lower mechanical characteristics. This mortar presented higher porosity and higher amount of large pores; that can justify their low strength.

In relation to dynamic modulus of elasticity, Röhlen & Ziegert (2011) define a large range, between 450-3000 N/mm². The mortars with addition of air lime are in this range while the others present higher values. Gomes et al. (2012) for earth mortars with addition of 5% of hemp fibers (thicker than the oat fibers) and 5% of air lime obtained lower values whereas for flexural and compression strength obtained higher resistance. Faria et al. (2014) analyzed air lime-based mortars with partial replacements of lime up to 50% (on 1:2 per volume mortars) or siliceous sand up to 25% (on 1:3 per volume mortars). The earth mortar with 5% addition of lime tested in the present study register lower flexural and compressive resistance.

2.3 Capillary absorption and drying

The capillary absorption of the mortars was assessed, based on EN 15801(CEN, 2009) and EN 1015-18 (CEN, 2002), by sequential weighing of the samples in contact with water to a height of 5 mm and using specimens with 40mm x 40mm x 40mm that were cut from the prismatic samples. The lateral faces were waterproofed with an epoxy resin. A thin cotton tissue was applied on the top down of the samples, to contain eventual mass loss of fines, and was maintained by a thin elastic band. Each sample was placed inside a net basket, in order to be handled throughout the test (Figure 2 (a)). The capillary curve, with water capillary absorption by contact area with water in ordinate (in kg/m²) and the square root of time in abscissa (in min^{0.5}), was plotted (Figure 3 (a)). The capillary coefficient, CC, represents the initial capillary absorption and was determined by the slope of the initial and most representative segment of the capillary curve.

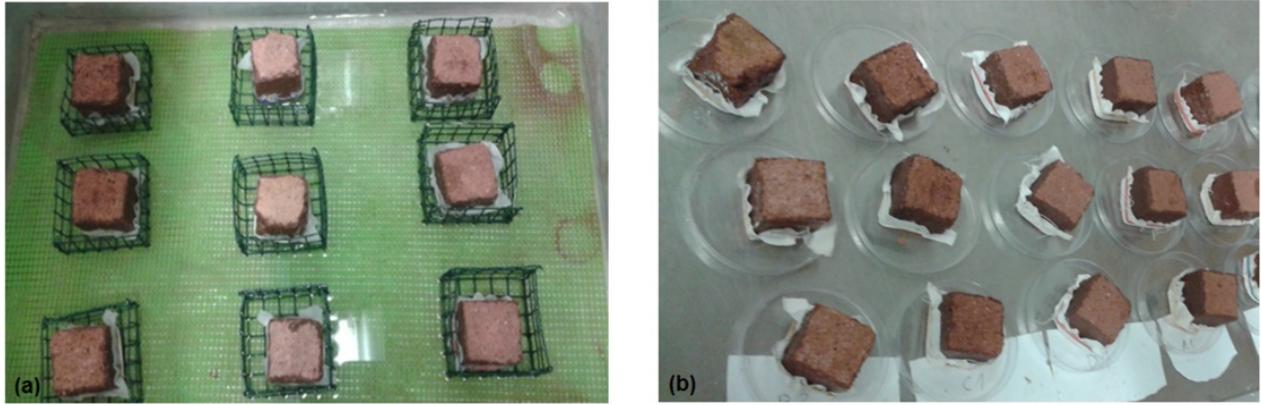


Figure 2. Mortar samples being tested for: (a) capillary and (b) drying.

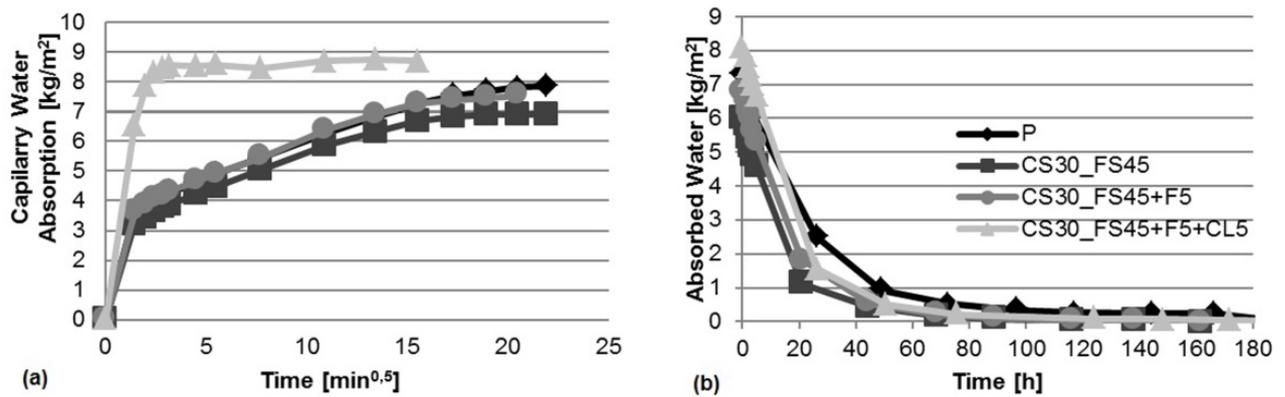


Figure 3. Capillary curves (a) and drying curves (b).

The drying capacity of the mortar was assessed after samples had been wetted by the capillary test, as described by EN 16322 (CEN, 2013), but without complete saturation of the samples and under controlled environmental conditions (Figure 2 (b)). The drying could only proceed by the top of the samples and it is expressed by the drying curve with absorbed water per drying area in ordinate (in kg/m²) and time (in h) in abscissa (Figure 3 (b)). The drying rate (DR) represents the initial drying of the mortar and was determined by the slope of at least 5 successive points of the drying curve for each mortar. The drying index (DI) represents the difficulty of achieving complete drying, in equilibrium with environment, and was calculated for a period of 140 h. Table 3 presents the capillary coefficient, drying rate and drying index.

Table 3. Capillary coefficient, drying rate and drying index of the mortars.

Mortar	CC [kg/(m ² .min ^{0.5})]	DR [kg/(m ² .h)]	DI [-]
P	2.52	0.18	0.20
CS30_FS45	2.27	0.23	0.12
CS30_FS45+F5	2.56	0.23	0.14
CS30_FS45+F5+CL5	4.63	0.25	0.14

It can be observed that the addition of air lime promotes an increase of capillary coefficient. The addition of fibers without air lime allows the formulation of a mortar with similar capillary coefficient to the ready-mixed mortar (also with fibers), while without fibers the mortar presents a lower and more positive value.

The laboratory formulated mortars present a faster initial drying (higher drying rate) compared to the ready-mixed mortar, being the mortar with lime slightly faster. Similar tendency is presented in terms of drying index, being the formulated mortars the ones with

easier total drying capacity (lower drying index), compared with the ready-mixed mortar, being the formulated mortars with lime the better. It is possible to conclude that the mortar which has a more positive behavior in terms of capillarity and drying is the formulated mortar without additions, being the mortar with lime particularly disadvantageous for capillary absorption. The capillary coefficient depends on the pore size and their connectivity, more porous mortars having higher values. The negative behavior of the mortar with lime can be justified given that it has more and larger pores. The use of lime may lead to an intensification of moisture-related anomalies in the wall-rendering system (Gomes et al., 2016).

2.4 X-ray diffraction

X-ray diffraction test (XRD) was carried out with a Phillips diffractometer with Co K α radiation, speed of 0.05 °/s and 2 θ ranging from 3 to 74. Two types of mortar fractions were analyzed: global fraction (GF), obtained by grinding the mortar samples as collected, and a fine fraction (FF), which was obtained from the fines of the mortar samples, both passing a 106 μ m sieve. The results obtained by XRD of mortars are presented on Table 4, in qualitative terms.

Table 4. X-ray diffraction on global and fine fractions.

Identified crystalline compounds	P		CS30_FS45		CS30_FS45+F5		CS30_FS45+F5+CL5	
	GF	FF	GF	FF	GF	FF	GF	FF
Quartz	+++	++	+++	++	+++	++	+++	++
K-Feldspar	++/+++	+	++	+	++	+	++/+++	+
Illite	+	++	+	++	+	++	+	+/++
Kaolinite	Vtg	+	Vtg	+	Vtg	+	Vtg	+
Hematite	Vtg	Vtg/+	Vtg	+	Vtg	+	Vtg	+
Calcite	-	-	-	-	-	-	+	++
Dolomite	+	++	+	++	+	++	+	++

Comparing P and CS30_FS45 mortars it is possible to conclude that there are no substantial differences in their mineralogical compositions, although the mortar P presents a higher proportion of feldspar. As expected: in the fine fraction an intensification of clay minerals is observed (mica, kaolinite and dolomite); the addition of fibers has no effect on the mineralogy of mortars; the presence of calcite is intensified in the mortar with air lime addition. No other compounds are detected, showing that the lime did not react with the earth. Nevertheless the lime may act as a blocker of the clay structure, inhibiting the characteristics of the clay, like its swelling, and leading to a different structure of the mortar matrix (Gomes et al., 2016).

CONCLUSION

From the study of these earth mortars it is possible to conclude that the addition of 5% of air lime causes a loss of mechanical strength and an increase of capillary absorption without significant changes on drying. This negative influence can be justified by the higher pore size and porosity. XRD has proven that there is no reaction between the lime and the clay but the inclusion of the small percentage of lime (5%) may inhibit the natural characteristics of the clay, namely its swelling, changing the mortar behavior.

A more complete characterization of earth-based mortars with different amounts of lime is ongoing in order to assess durability for renders. But for the time being it seems that the addition of low percentages of lime is not advantageous.

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