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Comparison of an earth mortar and common binder mortars for indoor plastering

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CONFERENCE PAPER

Abstract

Plasters can be formulated with different binders, presenting different characteristics. Their main function is the protection of the substrate but, as indoor coatings, their influence on aesthetic performance and indoor air quality and comfort is also important. A plaster formulated with a clayish earth is compared to plasters formulated with common binders, namely hemihydrate gypsum, air lime and natural hydraulic lime. All the plasters have the same volumetric proportion binder:sand and were produced with the same siliceous washed sand. Results show that: the linear shrinkage of the earth mortar was the highest while the gypsum mortar presented no shrinkage; the bulk density of all the mortars were similar but there were differences on thermal conductivity, with advantages for the lime mortars, although this property is not significant for plasters application thicknesses; the gypsum mortar presented the highest mechanical properties while the lime mortars presented the lowest, even lower in comparison to the earth mortar; however, the resistance to dry abrasion was lower for the earth plaster; the earth plaster registers a very high hygroscopicity in comparison to all the other plasters, being an important contribution to indoor comfort, occupants health and energy consumption reduction.

Keywords: plaster, clayish earth, gypsum, air lime, natural hydraulic lime

1. Introduction

Plasters are commonly used to coat indoor walls and ceilings, applied on new construction and repaired or replaced, when no longer functional, on existent buildings. Their main function is the protection of the substrates, but aesthetic performance is also considered. Their effect on indoor air quality and occupants' comfort and health can be significant. Plasters can be formulated with different binders, some more common as gypsum, limes, cement, or using clay as the binding agent.

Earth-based mortars are present all over the world in an extensive range of building types, from vernacular architecture to monuments. Nowadays plastering is one of the most common applications of earth-based mortars, used for earthen-building conservation [1] or contemporary architecture, contributing for building energy performance and building life cycle sustainability [2]. When compared to conventional binders-based mortars, like gypsum, air lime, natural hydraulic lime or cement mortars, the earthen mortars can be considered more eco-efficient for indoor plastering [2]. This type of mortars is compatible with historical buildings materials [1], presents less embodied energy and its production does not directly lead to any pollutant emissions [2]. Due to the high hygroscopicity of clay minerals, earth-based mortars can act as moisture buffer, balancing indoor relative humidity and improving air quality, thus giving a significant contribution for the health and comfort of inhabitants [3]. However, earthen plasters are rarely compared to common binder plasters [4], namely based in hemihydrate gypsum, air lime, natural hydraulic lime and cement. Clayish earth does not require heat treatment while these common binders have progressively higher firing temperature for production, from 100-200ºC for gypsum, around 900ºC for air lime or slightly higher for natural hydraulic lime, to near 1500ºC for cement. The production sites are usually located near the raw material quarries, which influence transport distances from the factories to the construction sites. In the case of clayish earth, local raw material can be easily used.

Therefore, this study aims to compare physical, mechanical and hygroscopic properties of plastering mortars based in a clayish earth and in three different common binders, namely hemi-hydrated gypsum, air lime and natural hydraulic lime. Cement was excluded from this study due to its high embodied energy and because cement mortars high strength is often unnecessary for plasters. If a paint or other system is applied as a plaster finishing, results on hygroscopicity and surface abrasion of the plasters may change. Paint systems were common on vernacular earth plasters but nowadays this type of plasters use to be left unpainted to profit from their natural colours and texture. In this study, all the plasters were tested unpainted.

2. Materials and methods

2.1. Materials, mortars and fresh state characterization

The materials used to formulate the mortars were an illitic clayish earth (named E), a hemi hydrated gypsum from Sival Company (named G) [5], a powder hydrated lime from Lusical company, Lhoist group (referred as CL) [6] and a natural hydraulic lime from Secil Martingança (referred as NHL) [6]. Based on EN 459-1 [7] the air lime was classified as CL90-S and the natural hydraulic lime as NHL3.5. The clayish earth was picked in a quarry in Algarve, South Portugal, and was characterized in a previous study [3]. It was disaggregated before being used.

A siliceous washed fine sand, (named SF), extracted from a quarry in Sesimbra, Setubal region (South Lisbon) was also used. The loose bulk density of the clayish earth, the common binders and the sand is presented in Table 1.

Table 1. Materials loose bulk density.

	E	G	CL	NHL	SF
Loose bulk density [kg/m^3]	1317	652	351	705	1500

Notation: E – Clayish earth; G – Gypsum; CL – Air lime; NHL – Natural hydraulic lime; SF – Fine Sand

Both the earth and the sand were characterized by dry particle size distribution, based on EN 1015-1 [9]. The particle size distribution curves are presented in Fig. 1.

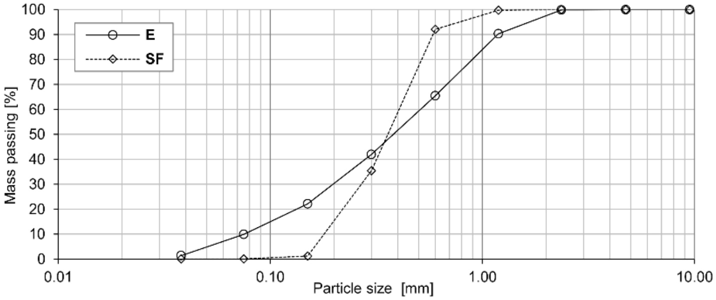

Fig. 1. Particle size distribution of the clayish earth E and the sand SF.

All the mortars were formulated considering a volume ratio of 1:3, respectively of clayish earth or one of the common binders, and sand. Therefore, they were designated according to the binder (E, G, CL or NHL) and the sand (SF) and their respective volumes. The mixing of the common binder mortars followed EN 1015-2 [10], while preparation of the earth mortar, in the absence of a specific European standard, followed the German standard DIN 18947 [11] for earth plasters. The kneading water was added to ensure an adequate workability. Mortars were characterized in the fresh state by flow table consistency, following EN 1015-3 [12] and wet density, according to EN 1015-6 [13].

Table 2 reports the mortars´ formulations in terms of both volumetric and weight percentages of clayish earth, common binder, sand and water contents.

Table 2. Composition and fresh state mortars characterization.

	Volume proportions						Weight proportions						Fresh state	Flow table
	E	G	CL	NHL	SF	Water$^{(a)}$	E	G	CL	NHL	SF	Water$^{(b)}$	density	consistency
Mortar	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[kg/m^3]	[mm]
E1SF3	25.0	0.0	0.0	0.0	75.0	24.6	22.6	0.0	0.0	0.0	77.4	77.4	2019	173.2
G1SF3	0.0	25.0	0.0	0.0	75.0	24.0	0.0	12.7	0.0	0.0	87.3	87.3	1936	175.9
CL1SF3	0.0	0.0	25.0	0.0	75.0	25.4	0.0	0.0	7.2	0.0	92.8	92.8	1958	169.6
NHL1SF3	0.0	0.0	0.0	25.0	75.0	25.6	0.0	0.0	0.0	13.5	86.5	86.5	1981	178.4

Notation: E – Clayish earth; G – Gypsum; CL – Air lime; NHL – Natural hydraulic lime; SF – Fine Sand; (a) – Volume added to the total volume of dry components; (b) – Mass added to the total mass of dry components.

2.2. Samples and hardened state characterization

For all mortars three types of samples were prepared. Prismatic samples, in metallic moulds of 40 mm x 40 mm x 160 mm, filled in two layers, each compacted mechanically. Planar samples, in metallic moulds of 15 mm x 200 mm x 500 mm, simulating a plaster application but without a substrate, based on DIN 18947 [11]. Samples simulating a 15 mm thickness plaster applied on hollow brick were also prepared, being the brick previously sprayed with water. All samples were let to dry in laboratory with controlled conditions of temperature (20±5°C) and relative humidity (50±5%). Only the prismatic samples were demoulded when dried. Hardened state tests were performed after 56 days, comprising 30 days of accelerated carbonation, in a CO_2 rich confined environment, for the mortars formulated with air lime and natural hydraulic lime. Samples carbonation was confirmed through phenolphthalein test, carried out on the fracture surface of the samples, immediately after the flexural strength test.

The mortars´ hardened state characterization followed EN 1015 standards and the German standard DIN 18947 [11] for earth-based plasters, which partially remit also to the EN 1015 standard series. Mortars were characterized in terms of: drying shrinkage, measuring the linear shrinkage of the planar samples, adapted from DIN 18947 [11]; bulk density, by measuring the mass of prismatic samples with a 0.001 g precision digital scale, divided by their volume, measured with a digital calliper, according to EN 1015-10 [14]; thermal conductivity, with an ISOMET 2104 equipment with a API 210412 contact probe with 60 mm diameter, with a measurement range of 0.3 to 2.0 W/(m.K); dynamic modulus of elasticity with a Zeus Resonance Meter ZMR 001 equipment, based on EN 14146 [15]; flexural and compressive strengths with a Zwich Rowell Z050 equipment, with load cells of 2 kN and 50 kN, respectively, according to EN 1015-11 [16]; adhesive strength of the plasters on brick, based on EN 1015-12 [17] but using the previous Zwick equipment; dry abrasion, by the mass loss imposed by 20 cycles made by a circular brush in the plaster on brick surface, according to DIN 18947 [11]; dynamic water vapour adsorption and desorption using the planar samples, based on DIN 18947 [11], with adsorption and desorption phases extended beyond the defined 12 h, to a total time of 24 h for each phase.

3. Results and discussion

Table 2 shows that, except for the gypsum mortar, for a flow table consistence of 174 ± 5 mm, ensuring workability, the wet density of mortars increases directly with the binders´ loose bulk density (Table 1).

Fig. 2 presents the linear drying shrinkage of the planar samples. It can be observed that drying shrinkage of the earth mortar is much higher in comparison to the common binder mortars, although being considered a low shrinkage for an earth mortar, according to DIN 18947 [11] and other studies [3,4]. Gypsum mortar had no shrinkage record, while air lime and natural hydraulic lime mortars presented also low shrinkage, the latter having a slightly higher record.

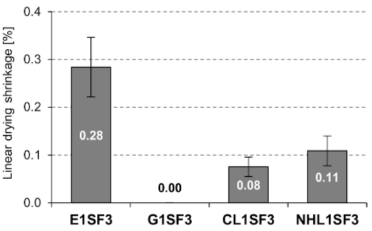

Fig. 2. Linear drying shrinkage assessed on prismatic and planar samples of earth, gypsum, air lime and NHL mortars.

Nevertheless, none of the mortars presented shrinkage cracking either in the plaster samples applied on hollow brick or in the planar samples in metallic moulds (Fig. 3). Fig. 3 also allows to see that the common binder plasters present a light cream to light grey colour, while the tested earth plaster is reddish.

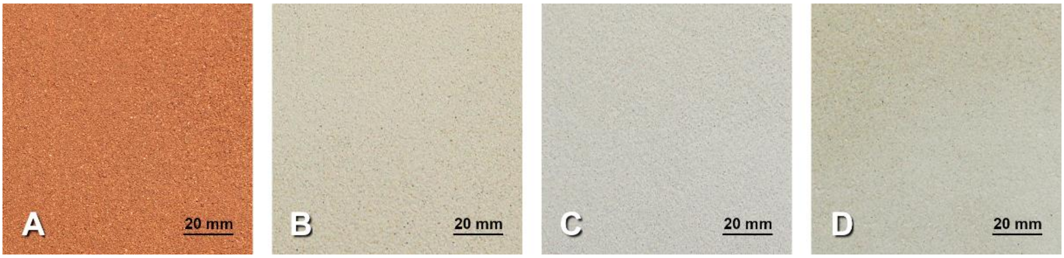

Fig. 3. Aspect of mortar planar samples showing absence of shrinkage cracking: (A) Earth mortar; (B) Gypsum mortar; (C) Air lime mortar; (D) Natural hydraulic lime mortar.

Fig. 4 presents the bulk density and thermal conductivity of all the mortars. One can see that while the bulk density is very similar for all the mortars, the thermal conductivity decreases from the earth plaster to the gypsum plaster, the air lime plaster and the NHL plaster. The difference between the latter and the earth plaster is near the double. However, being a plaster applied with relatively thin thicknesses, the influence on thermal resistance, that is obtained by the thickness divided by the thermal conductivity, is relatively low. The same would not happen when considering masonry bedding mortars.

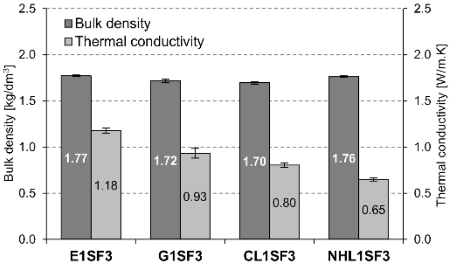

Fig. 4. Bulk density and thermal conductivity of earth, gypsum, air lime and NHL mortars.

Fig. 5 reports the results of compressive, flexural, and adhesive strengths, along with dynamic modulus of elasticity. The earth mortar mechanical resistance is clearly higher than air lime mortar and similar to natural hydraulic lime mortar, while the gypsum mortar presents by far the highest mechanical performance. High mechanical properties were also shown by Santos et al. [4] for a pre-mixed gypsum-based mortar. A strong correlation is observed between mortars dynamic modulus of elasticity and compressive and flexural strength which is also mentioned in previous studies [1,3]. A correlation is also reported between mortars dynamic modulus of elasticity and adhesive strength, although less significant.

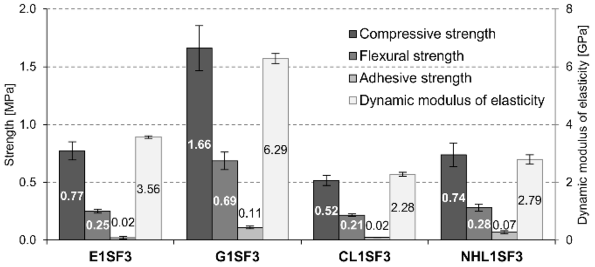

Fig.5. Compressive, flexural and adhesive strength and dynamic modulus of elasticity of earth, gypsum, air lime and NHL mortars.

Fig. 6 shows the mass loss by dry abrasion test carried on the plaster samples applied on brick. It can be observed that the resistance to dry abrasion is much higher for the NHL plaster, followed by the gypsum and air lime plasters, while it is much lower on the earth plaster. Comparing with the mechanical properties, dry abrasion resistance is not directly correlated.

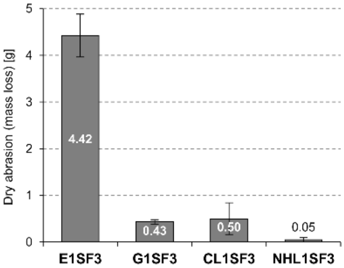

Fig. 6. Mass loss by dry abrasion of earth, gypsum, air lime and NHL plastering mortars.

Results of dynamic vapour adsorption and desorption test, reported in Fig. 7, clearly show that the earth mortar presents, by far, the highest vapour adsorption and desorption capacity, in agreement with results of previous studies [3,4]. The natural hydraulic lime mortar presents the second highest vapour adsorption and desorption capacity, showing more than the double of the gypsum mortar or the air lime mortar. This is a surprising result, considering that gypsum and air lime mortars are recognized by having high hygroscopicity. However, low hygroscopicity of a pre-mixed gypsum-based plaster was also recently registered by Santos et al. [4], similar to an earth-air lime plaster also studied by the same researchers.

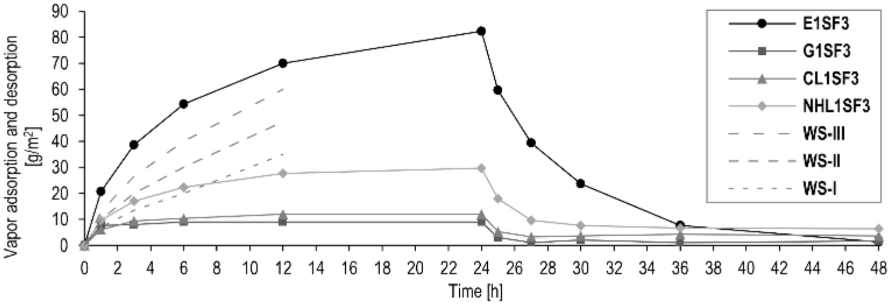

Fig. 7. Water vapour adsorption and desorption of earth, gypsum, air lime and NHL plasters and WS adsorption classes of DIN 18947.

A relatively pronounced desorption hysteresis effect is noticed for common binder mortars while the earth mortar shows very low desorption hysteresis. Furthermore, the adsorption capacity of the common binder plasters seems to stabilize after 12 h, while the same capacity of the earth plaster is still growing, at least up to 24 h, when the test adsorption phase stopped.

Comparing with the DIN 18947 [11] adsorption classes for earth plasters, one can see that the gypsum and air lime plasters could not be classified, the NHL plaster achieves the lowest WS-I class but only up to 6 h while the earth plaster surpasses the limits of the highest class WS-III.

4. Conclusion

The gypsum mortar had no shrinkage record while the earth plaster presented higher linear shrinkage in comparison to the other tested common binder plasters; however, the earth plaster shrinkage can be considered low for an earth mortar and is within limits to avoid cracking. The thermal conductivity is also more advantageous for the lime plasters, although the difference will not be significant in terms of a wall thermal resistance, due to the thin thickness of the plaster layer. The earth mortar presents interesting mechanical properties in comparison to air lime and natural hydraulic lime mortars. However, due to limited dry abrasion resistance, its use should be restrained to surfaces where this action is not too intense. For low strength plasters, such as earth and lime-based, the adhesion strength is low, what may be dependent on the test method used.

Conclusions highlight that the assessed earth mortar presents mechanical performance suitable for plastering, either in earthen-building conservation or contemporary architecture buildings. The earth mortar shows very high adsorption and desorption capacity, even compared with the more hygroscopic common binder-based mortars, which allows to anticipate that this type of earth mortars, when used for indoor plastering, can in fact act as a moisture buffer, significantly contributing to the equilibrium of indoor hygrometric conditions, thus to the health and comfort of inhabitants, and therefore to building energy performance and life cycle sustainability.

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