

Air lime-earth blended mortars - Assessment on fresh state and workability

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ABSTRACT: Air lime-earth blended mortars have been widely used as masonry, rendering and plastering mortars, mainly for stone or earth masonries. Nevertheless, there is a gap in the scientific knowledge about the characteristics of this type of mortars. Fresh state characteristics of mortars affect workability but also hardened state characteristics. Due to these reasons, an experimental campaign was started with air lime mortars, where lime or fine sand was partially replaced by a clayish earth. Consistency, bulk density, air and water content were determined, compared with water intake of the fresh mortars and with mechanical strength. Simultaneously, workability and shrinkage were evaluated through the applications on substrates – on brick in laboratory conditions and on a rammed earth wall on natural exterior environment. The results show the influence of the earth percentage on air lime-earth blended mortars but particularly that this type of mortars can have very good workability, mechanical resistance similar to pure air lime mortars and fulfill the requirements for rendering mortars.

1 INTRODUCTION

Earth mortars have been widely used in the past and they still belong to the craftsman knowledge in many regions of the world. They were used as stone or adobe masonry mortars and as plastering mortars to protect the interior surface of walls. Whenever they needed to be applied as rendering mortars, generally an amount of air lime was added to the earth and air lime-earth blended mortars were formulated. Earth-based mortars were applied as renders and plasters on earth-based walls (adobe masonry walls, rammed earth or wattle and daub walls) but also over stone masonry walls.

For some decades the use of earth-based mortars almost stopped in many countries of Europe, mainly substituted by cement mortars. Since the 80's the incompatibility of cement mortars was perceived and lime mortars slowly re-began to be used (Veiga et al. 2010; Arizzi et al. 2012). Only in recent years the advantages of the application of earth-based mortars regained interest. An example of the interest in non chemically stabilized earth mortars are the new Germany standards for earth plaster and earth masonry mortars, showing the need of defining requirements for this type of building products (NABau 2013a,b).

In the past, renders were applied in successive layers, with air lime mortars or with air lime-earth blended mortars, often with lime-wash paint

finishings; earth mortars were not normally used due to insufficient resistance to the action of rain.

In Portugal there are still almost entire villages, mainly in the Alentejo region, which are built with earth (Correia 2007). The earthen walls can only be detected when the renders are no longer efficient; that can be due to natural aging deterioration, often accelerated by problems of capillary rise of water.

When degradation appears, the owners often resort to unskilled craftsmanship, who applies cement-based mortar renders and plasters, not compatible with the earth walls. This type of mortars, instead of effectively contribute for the walls' protection, accelerate its degradation (Gomes & Faria 2011; Gomes et al 2013). In fact the protection and conservation of existing earth walls depend on the application of renders that have to be compatible with the wall materials and the pre-existing mortars.

Beyond the necessary compatibility between materials, another relevant aspect is the sustainability of the construction. The growing concern about this matter leads to an increasing research about earth-based materials. In fact, compared to other building materials, the life cycle energy cost of earth is minor because there is no energy consumption for its production process, a small amount of energy is required for milling and normally the energy for transportation is reduced (sometimes can be dug on site).

Conventional air lime mortars have been the subject of numerous studies and therefore there is now a

wide range of reference values related to this type of mortars (Faria et al. 2008, Veiga et al. 2010, Arizzi et al. 2012). Nevertheless, most of the available results are related with hardened mortars.

Available results about earth mortars are substantially less frequent compared to air lime mortars. Several authors have been researching topics related with earth mortars (Gomes et al. 2012; Hamard et al. 2013; Faria et al. 2014) but very few results have been focusing on the mortars characteristics in the fresh state (Azeredo et al. 2008). Gomes et al. (2012) have studied the influence of water in the workability of earth mortars to be applied for the repair of rammed earth walls and demonstrated the strong influence that the water/dry material ratio really have on the workability and shrinkage of these mortars. However, almost no researches have focused on studying air lime-earth blended mortars (Fernandes et al. 2012). Therefore, and although the large use of air lime-earth mortars for earth or stone wall renders in the past, nowadays there is a gap in the knowledge on air lime-earth rendering and masonry mortars and namely about its characteristics in the fresh state. With the growing of interest on this type of mortars, their characterization has become extremely important.

Motivated by all the previous aspects, the present paper will characterize air lime-based mortars with replacements of lime or fine sand by a clayish earth. The objective is to achieve a method to design mortars that are compatible with rammed earth and other masonries with similar characteristics (like adobe and stone masonry) and that may be used for the new rendering of walls but particularly for the repair or substitution of existing renders and re-pointing of masonry joints.

2 EXPERIMENTAL CAMPAIGN

Two customary air lime mortars were formulated, with volumetric proportions 1:2 and 1:3 (air lime:sand). They are considered reference mortars L2 and L3. The study follows two strands, both with increasing use of clayish earth. Based on the 1:2 proportion, four partial replacements of the binder with earth were made, while based on the 1:3 proportion, four partial replacements of the finer fraction of aggregate with earth were made. The entire process of mixing, preparation of samples and testing was performed in sequential batches.

Tests were performed in all the fresh mortars for the assessment of flow table consistency, fresh bulk density, air content and water retention.

A layer of all the mortars was applied on the surface of ceramic hollow bricks and let to dry in laboratory controlled conditions, while the reference mortars and two other mortars with defined earth

percentages were applied as rendering systems on a rammed earth experimental wall.

To be able to compare the mortar in terms of mechanical resistances, flexural and compressive strength was also assessed.

2.1 Materials

The air lime L used for the mortars was a CL90 supplied by Lusical (Lhoist Group), which has been characterized chemically by XRD analysis elsewhere (Gameiro et al. 2014) and was characterized for loose bulk density (Table 1), based on EN 1097-3 (CEN 1998) - with a free fall of the dry material on a beaker of known volume without any compaction, only eliminating the excess of material.

Table 1. Loose bulk density of air lime, earth and aggregates.

Material	Loose bulk density [kg/dm ³]
Air lime L	0.362
Earth E	1.084
Coarser sand CS	1.412
Medium sand MS	1.405
Finer sand FS	1.388
Mixture of sands	1.463

The sand used for the mortars was composed by a mixture of three washed siliceous graded sands, based on a volumetric proportion of 1:1.5:1.5 (coarse sand CS, medium sand MS and fine sand FS). Each one of the sands and the mixture of sands were characterized in terms of loose bulk density (Table 1) and particle size distribution by dry method, performed according to EN 933-1 (CEN 2000) (Fig. 1).

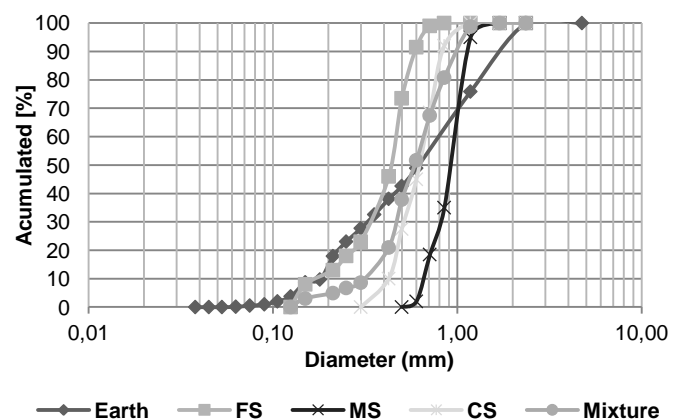


Figure 1. Particle size distribution of each sand, the mixture of sand and the clayish earth by dry methods (Credits: authors).

The earth used was supplied by Sorgila (a clay supplier company) and was from Redinha, Pombal, Portugal. It was subjected to crushing in a grinding mill, in order to disaggregate the lumps initially present and then characterized: in terms of particle size

analysis, by dry method, also performed according to EN 933-1 (CEN 2000) (Fig. 1); by the loose bulk density, according to EN 1097-3 (CEN 1998) (Table 1). In a previous publication (Faria et al. 2013) the same earth has been also characterized in terms of particle size distribution by wet method and mineralogical composition by XRD.

2.2 Mortars and samples

Based on the 1:2 reference mortar (L2), the following weight percentages of air lime were replaced by earth: 5%, 10%, 25% and 50%. Regarding the 1:3 reference mortar (L3), the following weight percentages of the finer aggregate were replaced by earth: 5%, 10%, 15% and 25%. The ten mortar compositions are presented in Table 2. The designations of the mortars include the reference mortar (L2 or L3), the percentage by weight of clayish earth (a number followed by E), replacing lime (L) or fine sand (FS). The composition of the mortars is presented in terms of weight and volumetric proportions, as well as by the water/lime (W/L) and the water/earth (W/E) weight ratios (Table 2).

Table 2. Mortars composition and water/lime and water/earth ratios.

Mortar	Weight proportion	Volumetric proportion	W/L	W/E
	L:E:S	L:E:S	[-]	[-]
L2	1:0:7.7	1:0:2	0.17	-
L2_5E(L)	1:0.05:8.1	1:0.02:2.1	0.18	35.4
L2_10E(L)	1:0.1:8.6	1:0.04:2.2	0.18	17.7
L2_25E(L)	1:0.3:10.3	1:0.1:2.7	0.18	7.1
L2_50E(L)	1:1:15.5	1:0.3:4	0.18	3.5
L3_25E(FS)	1:1.1:10.5	1:0.4:2.7	0.28	2.6
L3_15E(FS)	1:0.6:11	1:0.2:2.8	0.26	4.0
L3_10E(FS)	1:0.4:11.2	1:0.1:2.9	0.26	6.0
L3_5E(FS)	1:0.2:11.4	1:0.07:2.9	0.26	12.0
L3	1:0:11.6	1:0:3	0.25	-

The mixing of the mortars was based on EN 1015-2 (CEN 1998) procedures established for mortars but adapted for the particular materials involved. The methodology comprised the following steps: firstly, the dry constituents were weight, manually homogenized and placed in the container of the mechanical mortar mixer; the required amount of water was measured and introduced into the container in the first seconds of mechanical mixing; after 150 seconds, the mixer was stopped and the borders of the mortar were integrated with a spatula; the mixer operated for another 30 seconds.

The amount of water added for each mortar was defined to obtain applicable, workable mortars, with values of flow table consistency within the range of 150 ± 10 mm.

Prismatic samples 160 mm x 40 mm x 40 mm for mechanical resistance determination were prepared in metallic moulds. The compaction was mechanical while the leveling was manual. Samples were left to dry during 90 days in controlled laboratory conditions with $20 \pm 2^\circ\text{C}$ temperature and $65 \pm 5\%$ relative humidity (RH).

2.3 Tests

The consistency was determined by the flow table test based on EN 1015-3 (CEN 1999), which allows assessing the influence of water (Fig. 2, left).

The bulk density of fresh mortars was determined by the quotient of the mass of mortar in the fresh state divided by the volume of the vessel that it occupies. It was determined according to EN 1015-6 (CEN1998) by the shock method - tilting the vessel filled with the mortar about 30 mm on alternate sides, allowing to fall a total of 10 times into the rigid working table.

The air content of each mortar was determined in accordance with EN 1015-7 (CEN1998) and is obtained by filling the air spaces of the mortar with water and its measurement using a specific equipment (Fig. 2, right).



Figure 2. Flow table test (left) and air content test (right) (Credits: authors).

The capacity of the mortars to retain water in the fresh state was evaluated by the water retention test that was performed based on the draft standard prEN 1015-8 (CEN1999) but the contact between the fresh mortar with filter paper lasted for 10 minutes.

The workability of the mortars was directly assessed when all the mortars were applied creating a layer 1.5 cm thick on individual hollow ceramic bricks, with a surface area of 29 cm x 19 cm (Fig. 3, left). The shrinkage of the mortars was assessed by visual observation of the mortars' layer on hollow brick while drying in controlled environment ($T = 20 \pm 2^\circ\text{C}$ and $HR = 65 \pm 5\%$).

The workability and shrinkage were further assessed for four of the mortars that were applied as renders. Each render have 3.04 m^2 of surface and was applied on a rammed earth test wall facing East in exterior natural environment (Fig. 3, right). The renders were composed by two layers of the same mortar. The first layer, 0.5-1cm thick, was mixed with 10% more water than the following and was

applied with an irregular surface. The following layer had the same amount of water that was used for the samples production and completed the 2 cm thick render with a smooth surface. The mortars applied as renders were: both reference mortars, without any added earth (L2 and L3), and two air lime-earth mortars which showed good fresh state characteristics, L3_10E(FS) and L2_25E(L).



Figure 3. Mortar layer on hollow ceramic brick (left) and rendered panels on the rammed earth test wall (right). In the middle, the renders with air lime-earth blended mortars (Credits: authors).

As the application of the renders was made in winter time (with a lot of moisture) there was no need of water spraying the walls' surface or the mortar layers after application. Both substrates (the hollow ceramic bricks and the rammed earth) have been characterized elsewhere (Faria et al. 2013).

The prismatic samples were tested for flexural and compressive strength with a Zwick Rowell equipment with a 2 kN load cell for flexural (Fig. 4, left) and 50 kN load cell for compression (Fig. 4, right), based on EN 1015-11 (CEN 1999), after 90 days.

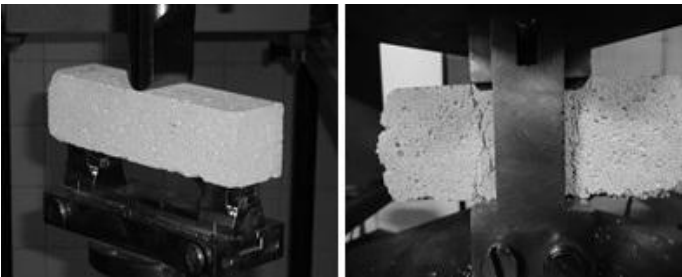


Figure 4. Flexural (left) and compressive (right) strength tests (Credits: authors).

3 RESULTS AND DISCUSSION

The consistency measured with the flow table (average value and standard deviation), the water retention and the water/earth weight ratio of the mortars are shown in Figure 5.

For the mortars based on composition 1:2 (L2...), the replacement of lime with earth causes an initial increase in consistency, except for the mortars with 25% and 50% of earth - L2_25E(L) and L2_50E(L). This last mortar registered the lowest value, with 145.8 mm. The mortar L2_10E(L), having 10% of earth, recorded the highest consistency.

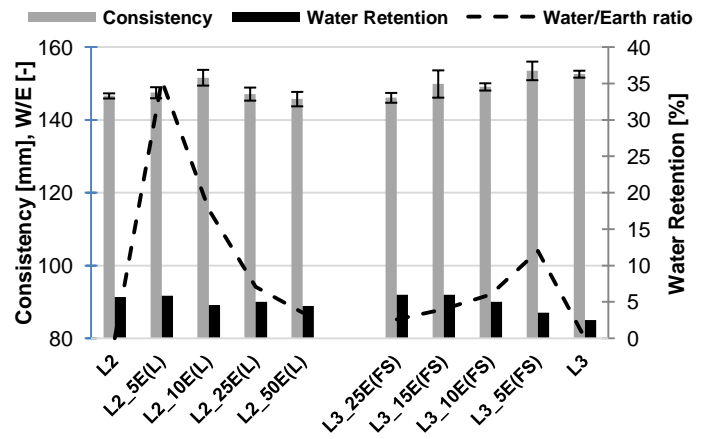


Figure 5. Consistency by flow table test, water retention and water/earth weight ratio of mortars (Credits: authors).

Comparing with the water/earth ratio of the mortars it can be remarked that, in general, the consistency decreases with decreasing ratio (with the exception of the mortar with 10% earth - L2_10E(L)). For the mortars with composition 1:3 (L3...) the mortars L3 and L3_5E(FS) are those with the highest values of flow table consistency - even higher than L2_10E(L). During this test it was possible to visually verify these results, since the increase in the percentage of earth significantly decreased the mortars' workability. The mortar L3_25E(FS) (with 25% of earth) had a very low workability. Due to the water/earth ratio of each mortar it is found that, in general, the consistency decreases with decreasing ratio.

The water retention seems to decrease with the percentage of earth in 1:2 mortars, while a clear increase is noticed in the 1:3 mortars, with the replacement of fine sand by earth. The difference in results and trends appear to indicate that the earth has less ability to retain water than lime (mortars 1:2), but obviously has higher water retention capacity than the fine sand (mortars 1:3). Although the maximum values recorded by the two families of mortars were in the same order of magnitude, the lower values were recorded by L3 and L3_5E(FS) mortars. It may indicate that, for these two mortars, curing process should be more careful to avoid a very fast release of water.

The bulk density and the air content of the fresh mortars can be observed in Figure 6. For the mortars based on composition 1:2, where earth partially replaces lime, it is possible to observe that the density tends to increase with the percentage of earth, indicating a greater compactness of the fresh mortar. For the mortars based on composition 1:3, where earth partially replaces fine aggregate, the progress suggests a reduction on density with increasing amount of earth. For that reason, the pure lime mortar with composition 1:3 (L3) have a much higher density than all 1:2 based mortars. Nevertheless, L2_10E(L) and L3_15E(FS) register quite similar bulk density.

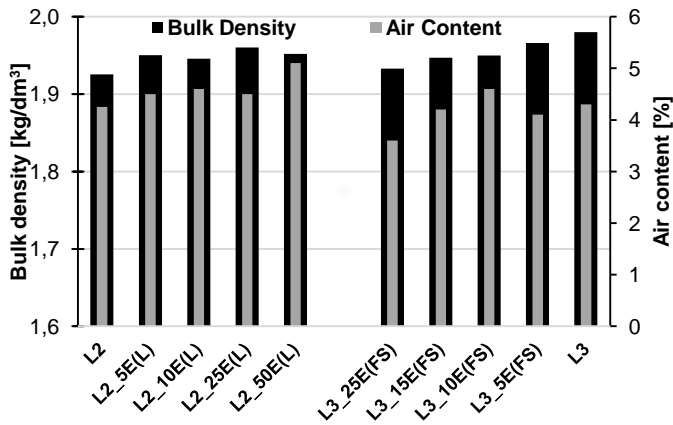


Figure 6. Bulk density and air content of fresh mortars (Credits: authors).

In terms of air content it can be noticed a slight tendency for increase with the percentage of earth on 1:2 mortars while for 1:3 mortars an inverse situation is indicated.

Concerning the application of the mortar layers on the brick, no difficulties appear in terms of workability. No shrinkage cracks were observed during drying. In terms of applicability of the mortars as renders on the rammed earth wall (rendering systems and bigger dimensions compared to the brick layers), the two mortars with earth demonstrated better workability than the reference mortars (without earth) during the application process. Visual observations were conducted during the hardening process of the four renders and there was no shrinkage cracking.

It is also important to notice how the earth affected the color of the rendered sections (Fig. 3, right – two middle sections). This aspect can be particularly interesting because it may eliminate the need for an aesthetic coat of paint.

The flexural and compressive strength of the mortars assessed after 90 days are presented in Figure 7. It can be noticed that, both for mortars 1:2 and 1:3, the compressive strength decreases with the percentage of earth. However the mortar L2_10E(L) can be competitive compared with the reference mortars (L2 and L3). According to flexural strength, it is also perceptible that mortars with low percentage of earth (again both for L2... and L3... mortars) register high strength compared to the reference mortars, in particular L2_10E(L) and L3_10E(FS). It is interesting to notice that mortars L3_25E(FS) and L2_25E(L) show similar flexural resistances.

Veiga et al. (2010) suggested that the most compatible mortars to be applied on rendering and plastering systems or for re-pointing of historic masonry should register characteristics within defined ranges. Nevertheless these ranges are merely indicative.

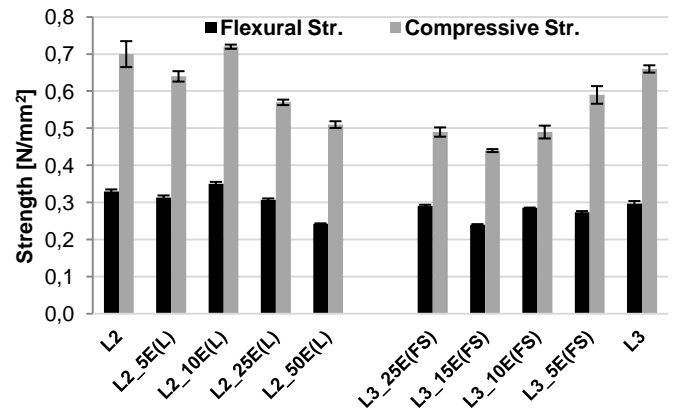


Figure 7. Flexural and compressive strength of mortars after 90 days (Credits: authors).

For rendering and plastering, the indication is that mortars should have flexural strength of 0.2 - 0.7 N/mm² and compressive strength of 0.4 - 2.5 N/mm²; for re-pointing the ranges recommended are 0.4 - 0.8 N/mm² and 0.6 - 3.0 N/mm², respectively for flexural and compressive strength. Comparing the flexural and compressive strength of the formulated and tested air lime-earth blended mortars with the ranges suggested by Veiga et al. (2010), it can be noticed that:

- all the mortars are within the range for rendering and plastering in terms of flexural strength and compressive strength;
- none of the mortars (not even the reference pure air lime mortars) fulfill the recommendation of minimal flexural strength for re-pointing;
- only mortars based on 1:2 formulation with 5% and 10% of earth, based on 1:3 formulation with 5% of earth and the reference mortars fulfill the recommendation of compressive strength for re-pointing mortars.

4 CONCLUSIONS

After the experimental campaign and analyzing the results, some observations can be taken. The quantity of water needed for the mortars production differs considering the amount of earth (and lime). The water conditions the workability of the mortars, which affects other characteristics, in the fresh and hardened state. Nevertheless, when tested on a small surface (bricks), all the formulated air lime-earth blended mortars seem to present adequate workability to be applied on site. That workability was even better than the one of pure air lime mortars - with 1:2 and 1:3 volumetric proportions - for mortars with 25% of earth replacing lime and with 10% of earth replacing fine sand, when tested for the application of renders on a test wall.

No other fresh state characteristic indicate problems for the tested mortars and drying shrinkage cracks were not detected.

The renders acquired natural pigmentation with the incorporation of earth, which can be beneficial when paint protective systems are not required.

Mechanical characteristics of the mortars after 90 days could be considered similar to pure air lime mortars for most of the air lime-earth blended mortars, particularly in terms of flexural strength. All the blended mortars indicate to be adequate for rendering and plastering historic masonry. Earth-based masonry can be considered to present mechanical and physical characteristics that are often comparable to historic masonry – with low mechanical strength and very porous, water vapor permeable microstructure. For that reason, and also based in traditional practices, it can be assumed that this type of blended mortars may also be adequate particularly for rendering earth-based masonry walls.

The use of air lime-earth blended mortars for rendering and plastering existent masonry walls can represent a significant eco-efficient improvement. In formulations where earth partially replaces the air lime, mortars can become more sustainable, with low embodied energy. Simultaneously, the knowledge of this traditional type of mortars and renderings can be re-gained, showing a path for more efficient interventions.

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