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Earth-based mortars for masonry plastering

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ABSTRACT: Earth mortars have been applied since unknown times. Their advantages are ecological but also cover several technical aspects, in terms of compatibility with masonries, reversibility, comfort, aesthetic and health. Some requirements of a recent German standard, which focus on non-stabilized earth plastering mortars, are presented. A commercial premixed Portuguese earth mortar was made within an ECVET workshop and applied as plasters on four different experimental masonry walls, at exterior environmental conditions. The plasters were observed during six months and characterized *in situ* by non destructive techniques, namely by ultra-sounds and for surface hardness. The same mortar used for the plasters was characterized in laboratory in fresh state and samples of mortar (only mortar and mortar layer applied on brick) were produced and characterized after drying. The characterization of the earth plasters applied on the walls and of the mortar samples is presented and discussed, showing the viability of their use as plaster for different masonry walls.

Keywords: *masonry; clayish earth; vegetal fibre; mortar; plaster; characterization*

NOTATION

ECVET	European Credit System for Vocational Education and Training
LNEC	National Laboratory of Civil Engineering
D	Dry bulk density [kg/m^3]
FStr	Flexural strength [N/mm^2]
CStr	Compressive strength [N/mm^2]
E_d	Dynamic modulus of elasticity [N/mm^2]
λ	Thermal conductivity [W/(m.K)]
V_{us}	Ultra-sound velocity [m/s]
SH_{dur}	Surface hardness by durometer [Shore A]
SH_{scl}	Surface hardness by sclerometer [Vickers]

1 INTRODUCTION

Earth plasters, produced with earthen-based mortars, have been widely used in the past and they still belong to the craftsman knowledge in many regions of the world. For some decades their use almost stopped in many countries of Europe. Only in recent years the advantages of their application regained interest. Dry premixed earthen mortars for masonry plastering are nowadays commercialized and applied as high standard plasters, namely in many occidental countries.

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Earth is a raw material that does not need energy for calcination, that can be found almost everywhere and sometimes (due to quality issues) can even be extracted from new building sites. That fact confirms the sustainability of earthen mortars, with a very positive life cycle. Only a limited energy is needed for milling the clayish earth to be used on mortars.

The colour, texture, eventually with the contribution of additions such as fibres, and granularity resulting from the application techniques, offers infinitive aesthetic possibilities to plasters made with earth mortars. Due to that aesthetic aspects paint coat systems may not be applied.

Furthermore, earthen plasters can contribute to improve the quality of living in interior environments, complementing the masonry requirements. In fact earthen mortar plasters present hygroscopic inertia that, within specific ranges, can help to regulate interior relative humidity [1, 2]; they present good capacity to absorb and give off moisture. The earthen mortar characteristics are compatible with low strength porous masonries, as the case of historic masonry, and are reversible once the clayish particles present water-soluble reversibility of its binding qualities. For the same reason, repairs are generally simple to undertake [3].

An example of the interest and actuality on earth plasters is the recent Germany earth plastering mortar standard [4], specific for mortars without any chemical stabilization - no other binder apart from raw earth. It shows the importance and need of defining requirements for this type of building products. Some of these requirements are defined in terms of the product itself, like the case of the limit of salts. The mortar products must not have more than 0.02% of nitrates, 0.10% of sulphates and 0.08% of chlorides. They must not exceed a total salt content of 0.12%. Other requirements are defined for hardened plastering mortars. In terms of dry bulk density D, determined by dimension measuring and weighting based on the DIN standard [4], the mortars are classified in classes, following Table 1.

Table 1. Dry bulk density classes [4]

D class	0.9	1.0	1.2	1.4	1.6	1.8	2.0	2.2
D range [kg/dm^3]	0.81–0.90	0.91–1.00	1.01–1.20	1.21–1.40	1.41–1.60	1.61–1.80	1.81–2.00	2.01–2.20

The linear shrinkage of earth mortars, without or with fibres, determined by measuring 160mm long samples, must not exceed 2% or 3%, respectively. Concerning strength classes, in terms of tensile, compressive and adhesion strength, mortars are classified following Table 2. Flexural and compressive strength are determined based on EN 1015-11 standard [5] and adherence is determined based on EN 1015-12 [6].

Table 2. Strength classes, conditioned by flexural (FStr) and compressive (CStr) strength and by adherence [4]

Strength Class	**FStr [N/mm^2]**	**CStr [N/mm^2]**	**Adherence [N/mm^2]**
S I	≥ 0.3	≥ 1.0	≥ 0.05
S II	≥ 0.7	≥ 1.5	≥ 0.10

In terms of resistance to dry abrasion, mortars are classified following Table 3, depending on the weight loss that occurs due to a defined abrasion of a hard rotating brush pressed against the plaster surface.

Table 3. Abrasion classes, in terms of weight loss [4]

Abrasion Class	Weight loss by Abrasion [g]
S I	≤ 1.5
S II	≤ 0.7

Concerning hygroscopicity, mortars are classified in terms of water vapour adsorption following Table 4. It depends on the water vapour gain recorded at predefined intervals of test, in a climatic chamber where relative humidity rises from dry to humid conditions (50% to 80% RH).

Table 4. Adsorption classes, in terms of weight gain after defined periods [4]

Adsorption Class	0.5h [g/m^2]	1h [g/m^2]	3h [g/m^2]	6h [g/m^2]	12h [g/m^2]
WS I	≥ 3.5	≥ 7.0	≥ 13.5	≥ 20.0	≥ 35.0
WS II	≥ 5.0	≥ 10.0	≥ 20.0	≥ 30.0	≥ 47.5
WS III	≥ 6.5	≥ 13.0	≥ 26.5	≥ 40.0	≥ 60.0

The DIN standard [4] defines some characteristics as specific and other characteristics as complementary. All these defined characteristics are to be tested in laboratory conditions and without depending on the type of support on which the plastering mortars will be applied. This is due to the fact that the DIN standard [4] in mainly focus on allowing the classification of products by the producers, in order to be commercialized (in Germany). But of course some other characteristics, namely those obtain *in situ* on plastering mortars, can be also determined.

Within a research being conducted within projects “Eco-Structural Wall” and “PIRATE” (Provide Instructions and Resources for Assessment and Training in Earth Building), a seminar and an ECVET workshop on earth plasters took place at the Faculty of Sciences and Technology of NOVA University of Lisbon (FCT UNL). The workshop was developed with the assistance of company EMBARRO. During the workshop, a commercial Portuguese earth mortar from this company was prepared and applied on different experimental walls located at the Experimental Station of FCT UNL. The Experimental Station of FCT UNL Campus is located approximately 3 km from the Atlantic coast. Alongside, several mortar samples were produced in laboratory with the same commercial earth mortar, from the same *in situ* batch.

It should be mentioned that the mortar preparation and the plaster application on the test walls was made *in situ* - and not in laboratory controlled conditions [7]. The characterization of the earth plastering mortars applied on the walls is registered and discussed, as well as some laboratorial characterization.

2 EXPERIMENTAL SAMPLES

A simple concrete foundation was prepared and left to dry (Figure 2 – left). Four different masonry test walls were made over the foundation, without any damp proof layer: rubble stone with limestone and air lime mortar, concrete blocks with cement mortar, adobe blocks with earth mortar (the same earth used to produce the blocks) and hollow bricks with cement mortar. The test walls were made one month before the application of the plaster, during summer time, and were left unprotected. The dimensions of the surfaces of the walls varied between 1.0-1.8 m height and 1.2-2.2 m length and the experimental walls can be seen in Figure 1 - left.

A commercial earth mortar, constituted by a clayish earth, sand with particle size distribution between 0-2mm and oat fibres with 1-2cm longer, was mechanically prepared with a quantity of water to allow an easy application, by a mechanical equipment (Figure 2 - left), and finishing (Figure 2 – right).

Figure 1. Four masonry test walls, yet unprotected – from the front to the back, rubble stone, concrete blocks, adobe and hollow bricks (left); protection of the experimental walls after plastered (right)

Figure 2. Mechanical mixing (left) and application (right) equipment

The mortar was directly applied on the four masonry test walls, after being sprayed with water (Figure 2 – right, for the brick wall). The plaster was easily levelled with a screed (Figure3, for the brick wall). The thickness of all the plasters was around 2cm.

The earth mortar was not chemically stabilized with any mineral binder and, for that reason, could be affected by rainfall. The plastered masonry test walls were protected by a continuous top covering with 2.2m two months after being completed. Fortunately there was not much rainfall during that period. Nevertheless and even with the top covering, as the South wind is very strong at the Experimental Station, it could be observed that degradation occurred at the underside of the south facing plaster panels, due to insufficient protection from rainfall. For that reason, a protection net was afterwards vertically positioned on the lateral sides of the test walls´ covering (Figure 1 - right).

Figure 3. Commercial earth plaster on the hollow brick test wall after projection (left), being levelled (middle) and finished (right)

Alongside, the mortar was characterized in laboratory in the fresh state (Figure 4 – left), in terms of flow table consistency (Figure 4 - middle), bulk density, water content and air content (Figure 4 - right). Several mortar samples were produced with the same commercial earth mortar, from the same *in situ* batch. Prismatic 40x40x160 [mm] samples were mechanically compacted in two layers on metallic moulds and superficially levelled (Figure 5 – left). Circular samples, with 60mm diameter and 15mm thickness, were produced in plastic moulds and manually compacted (Figure 5 – middle). For the production of samples of mortar on hollow brick, the bricks were previously water sprayed, the mortar were left to fall from 70 cm height to simulate the *in situ* application energy and then superficially levelled, presenting a mortar thickness of 1.5cm (Figure 5 – right).

Figure 4. Fresh mortar (left), consistency flow table test (middle) and air content determination (right)

The prismatic and circular laboratory samples were let to dry for several weeks and then de-moulded. Together with the mortar samples on brick, they were placed in a laboratory with 65±5% relative humidity (RH) and 20±3°C temperature.

Figure 5. Prismatic (left), circular (middle) and on hollow brick mortar (right) samples

3 TESTING AND EVALUATION

3.1. Water absorption of the masonry materials

The water absorption under low pressure was determined by Karsten tubes for the four masonry units: the limestone of the rubble stone masonry, the concrete block, the adobe block and the hollow brick. Results of water absorption after 1 hour test are registered in Figure 6. The absorption of the concrete blocks was so high that turned difficult the measurement of the water intake. In fact the water of each karsten tube (4ml) was immediatly absorbed by the concrete blocks and the maximum water absorption presented in Figure 6 is only indicative.

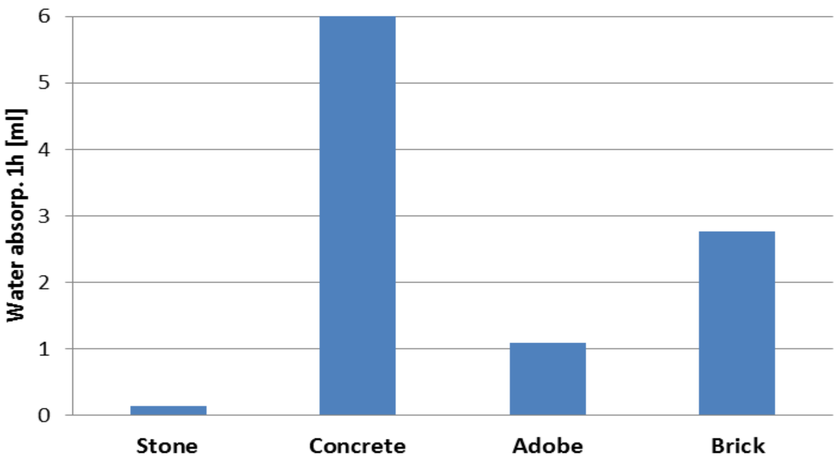

Figure 6. Water absorption under low pressure of the masonry materials

Particularly the total water absorption of the rubble stone masonry (with higher percentage of masonry mortar) but also of the other masonries will be affected by the water absortion of the correspondent masonry mortars. For that reason, the masonry units water absorption (Figure 6) is only indicative of the water absorption global behaviour of the masonries.

3.2. Workability, water and air content and shrinkage

As said before, the mortar´s workability was remarkably, both *in situ* and in laboratory. The flow table consistency was 178.8±2.5 mm (Figure 4).

The water content was registered by the weight difference between fresh and dried samples of the mortar and was 20.1±0.1%. The bulk density of the fresh mortar was 2.03 kg/dm^3, determined based on EN 1015-6 [8] and the air content of the mortar was 2.8%, following EN 1015-7 [9]. Only these two last characteristics were not determined by the average of at least three samples. That is why the standard deviation is not presented for those results.

Any shrinkage cracks could be visualized on the plaster panels applied on the four masonry test walls. The same happened with the mortar samples on hollow bricks. Following DIN 18947 [4], no shrinkage of the prismatic mortar samples was registered before de-moulding and, therefore, it was defined as lower than 3% (for mortars with fibres).

3.2. Dry bulk density and mechanical characteristics of prismatic samples

The dry bulk density D of the hardened mortar was determined based on DIN 18947 [4], by measuring and weighting of the prismatic samples, in equilibrium at 65% RH and 20°C temperature. The dynamic modulus of elasticity Ed was determined based on EN 14146 [10], using a Zeus Resonance Meter equipment (Figure 7 - left) and, according to DIN 18947 [4], the flexural and compressive strength, FStr and CStr (Figure 7 – middle and right), were determined based on EN 1015-11 [5]. Results, in terms of average and standard deviation, are presented on Table 5.

Table 5. Bulk density D, dynamic modulus of elasticity Ed, flexural and compressive strength, FStr and CStr, of prismatic mortar samples

Prismatic samples	D [kg/dm^3]	Ed [N/mm^2]	FStr [N/mm^2]	CStr [N/mm^2]
Average	1,77	3610	0,3	1,1
Stdv	0,02	128	0,04	0,08

Figure 7. Sample being tested for dynamic modulus of elasticity (left) and for compressive test - being tested (middle) and conic fracture (right)

According to Table 1, the mortar is classified in dry bulk density class 1.8. In terms of strength class, the mortar cannot be classified, as the adherence test had not been performed. But flexural and compressive results indicate that the mortar may be classified as S I.

Plastering (and rendering) mortars should always present mechanical characteristics, namely dynamic modulus of elasticity, that are lower than the ones of the masonry walls. Comparing these mechanical characteristics with the ones generally defined for masonries, it is clear that this mortar is suitable for being applied on diverse types of masonry walls. It is suitable for being applied for instance on historic masonry, with low mechanical characteristics [11]. The strength of non-chemically stabilized earth mortars does not depend on the age but only on the drying. Comparing the compressive strength with classes defined by EN 998-1 [12], the analyzed plastering mortar could be classified as CS I.

3.3. Thermal conductivity

The thermal conductivity of the earthen mortar on laboratory samples was determined at 65% RH and 20°C temperature by a Heat Transfer Analyser Isomet 2104 equipment, with a 60mm contact probe API 210412. The equipment test specification requires a minimal thickness of 1.5cm of the sample. The thermal conductivity λ was determined with the circular samples but also with the mortar samples on hollow brick (Figure 8 – left and middle). Results, in terms of average and standard deviation, are registered on Table 6.

Figure 8. Mortar on brick (left) and circular samples (middle) being tested for thermal conductivity and equipment for ultra-sound determination (right)

Table 6. Thermal conductivity on laboratory samples

λ [W/(m.K)]	Circular Samples	Samples on Brick
Average	1.3	0.9
Stdv	0.03	0.09

Some influence of the support can exist on the mortar samples on brick due to the fact that the mortar microstructure is likely to change due to the influence of the support and namely its suction. But the determination of the thermal conductivity with that effect (on samples on brick) can also be particularly interesting. Similarly, these samples are more representative of *in situ* application technique, while for the smaller circular samples, the effect of manual filling and compaction can be less representative.

It can be noticed that the thermal conductivity of the circular samples is similar to the one generally defined for lime mortars (1.30 W/(m.K [13]), while it decreases for samples on brick. The fact that samples on brick have the effect of the suction of the support and were applied more similarly to real *in situ* conditions demonstrates to be positive in terms of thermal conductivity.

3.4. Ultra-sound velocity and surface hardness by durometer and sclerometer

The ultra-sound velocity on the samples of mortar applied on brick (Figure 8 – right) and on plaster panels on the experimental wall (Figure 9 - left) was determined with a Proceq Pundit Lab equipment, conic transducers and a frequency of 54 Hz, based on LNEC test specification Fe Pa 43 [14]. Through this test the compactness and the presence of eventual defects (like cracks or detachments) can be detected. The thickness (from the surface) of material that is analyzed depends on the distance between the transducers; when transducers are more distant from each other, the thicker the thickness that is crossed by the ultra-sounds - and analyzed.

The surface hardness was determined with a PCE durometer Shore A (Figure 9 - middle), based on ASTM D2240 [15], and with a pendular sclerometer Schmidt PT (Figure 9 - right), based on ASTM C805 [16]. The sclerometer was only applied on the plaster panels and not on the brick mortar samples because the impact of the test could damage these last samples.

Figure 9. Ultra-sound (left), durometer (middle) and sclerometer (right) tests on plasters on the masonry test walls

The average and the standard deviation results of ultra-sound velocity, surface hardness by durometer and sclerometer are presented in Figure 10.

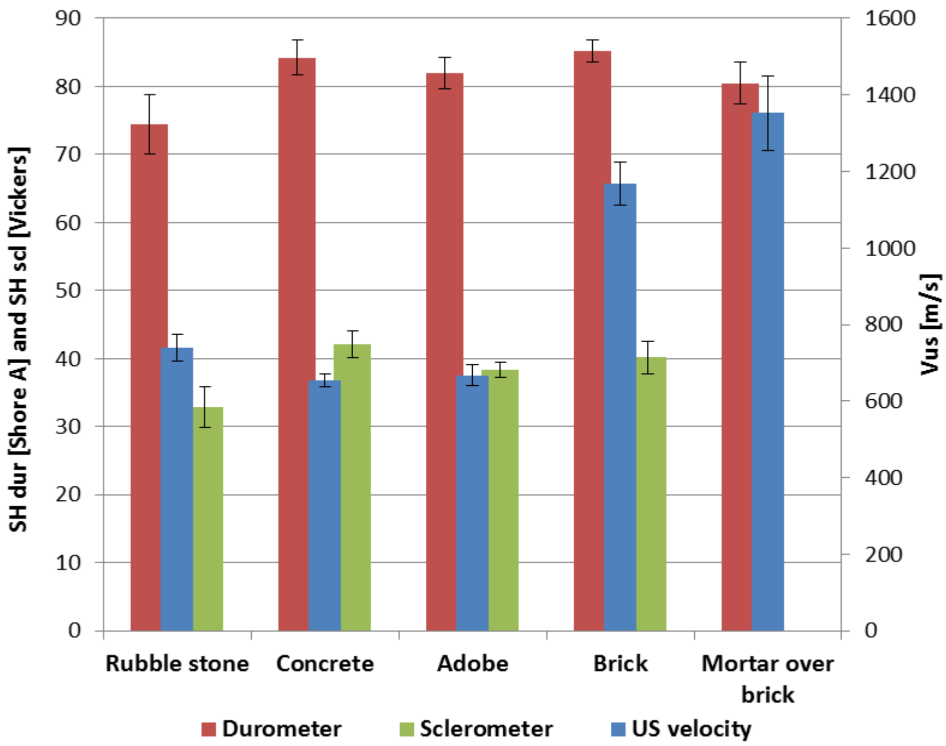

Figure 10. Ultra-sound velocity (V_{us}) and surface hardness by durometer (SH_{dur}) and by sclerometer (SH_{sc}) of the plasters on the masonry test walls and on samples of mortar on brick

It can be noticed that the ultra-sound velocity is much higher when the mortar is applied on brick masonry (and on brick samples), compared to the other types of masonry. This may be due to the fact that rubble stone and adobe masonries are compact walls. The concrete blocks also present a much higher thickness of the superficial face, compared to hollow brick, which ceramic shell does not even achieve 1 cm thickness. Comparing the brick masonry with the concrete block masonry it can also be due to the fact that the water absorption under low pressure of the concrete blocks is much higher than the one of the bricks (Figure 6). For that reason, the mortars´ microstructure may be differently affected by the type of masonry. This aspect will have to be further studied, namely by porosimetric tests, in the continuity of the present study. It can also be mentioned that the standard deviation is higher for brick samples. That can be due to the fact that, when the transducers are more distant from each other, it is more probable that the ultra-sound can reach the shells of the individual bricks in the samples. This is due to the fact that the mortar layer is a little less thick compared to the plasters on the brick masonry wall.

Concerning the superficial hardness, both by durometer and pendular sclerometer, it can be noticed that results, although in different scales, indicate the same tendency: the surface hardness seems to be lower for the plaster applied on the rubble stone masonry, while it is similar for the plasters applied on concrete, adobe and brick masonries.

3.5. Visual evaluation over time and related aspects

The plasters applied on the test walls were visually observed throughout six months and the following points should be mentioned. As said before, degradation occurred on the underside of the plasters facing south, due to rainfall projected by wind before the protective net was applied. A reduction of clayish particles could be observed, being the particles of sand more visible (Figure 11 – right) in comparison with the same plaster but in protected area (Figure 11 – left). As expected and defined by the producer, this mortar can be applied as plaster but not currently as render. As render it can only be applied when completely protected from rainfall. In all the surfaces, in exterior environment but water protected, no degradation was noticed.

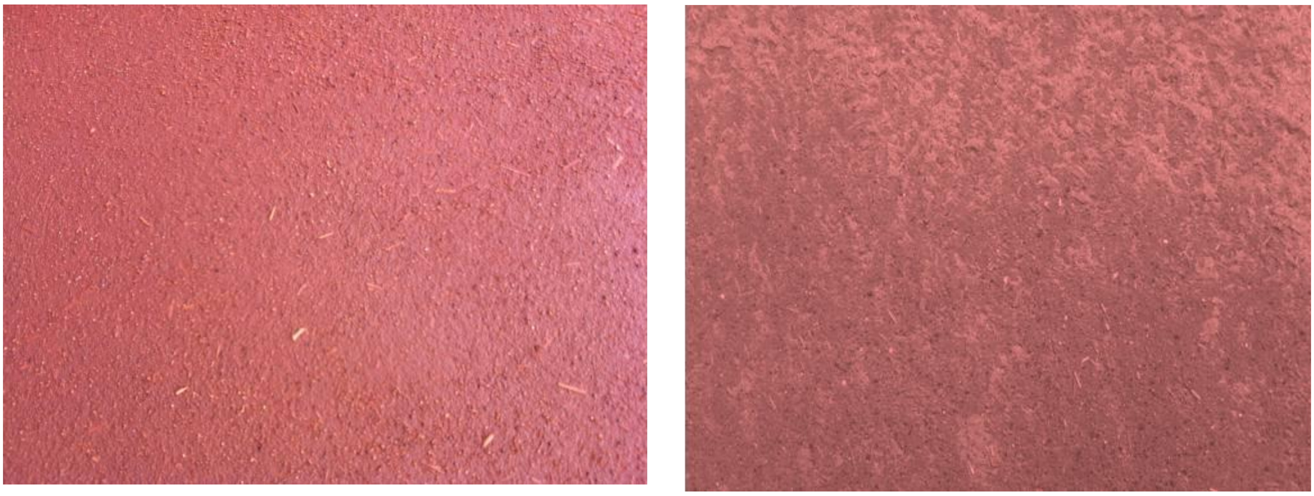

Figure 11. Visual observation of the plaster applied on one of the experimental masonry walls: protected area (left) and unprotected area (right)

Also as said before, the pendular sclerometer test generates a high impact on the surface of the plasters applied on the masonries. This impact is generally enough to cause the detachment of plasters when adherence is not efficient. No degradation was registered due to the sclerometer impact on any masonry plaster panel on the four masonry test walls, indicating that the adherence to each one of the four different types of masonry was in fact efficient.

Finally, the natural pigmentation of the plaster and its texture, with the effect of the vegetal fibres, must be mentioned (Figure 11- left). The fact that it does not need to be coated by a paint system for aesthetic reasons may eliminate the consumption of resources. At the same time the uncoated surfaces of the plasters will be able to contribute for the regulation of the relative humidity of the interior environment [17].

4. CONCLUSIONS

The main observations from the present study are:

- the very good workability of the earthen mortars and the easiness of its application, namely by mechanical projection and manual levelling, on plastered panels on four different masonries with areas that arrive to 4 m^2;
- the absence of drying shrinkage cracks when applied over rubble stone, adobe, concrete and hollow brick masonry;
- the aesthetical colourful and textural aspect that has been achieved;
- the good mechanical results obtained with the hardened mortar samples in the laboratory, indicating their classification as S I based on DIN 18947 [4] and as CS I following EN 998-1 [12];
- the effective adherence to the different types of masonry, although indirectly assessed by the impact of a pendular sclerometer and by ultra-sound velocity;
- the correspondence on surface hardness of the plastered panels by both non destructive methods – durometer Shore A and pendular sclerometer;
- the positive influence of the brick on thermal conductivity, probably due to changes on mortars´ microstructure by application similar to real conditions;
- as expected, the lack of durability of the plaster when subjected to rainfall;
- the good behaviour of the plasters applied over rubble stone and adobe masonries, but also over concrete and hollow brick masonries, after six months on exterior water protected environment.

The results that have been achieved show that this type of plaster indicate mechanical compatibility with historic masonry (rubble stone, adobe) but also that their range of application can extend for many other types of masonry, and namely to customary masonry (hollow brick, concrete blocks). The advantages of earthen plasters are then ecological but also technical, and these are reasons that sustain more frequent applications of this type of mortars.

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