Assessment of adhesive strength of an earth plaster on different substrates through different methods

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Abstract

The adhesion capacity of an earthen mortar is one of the most important properties for plastering. This paper aims to assess the influence of two different substrates, namely adobe and hollow fired clay bricks, in the adhesive strength of an earth plastering mortar formulated in laboratory, through tensile and shear tests methods. The substrates are prepared differently, with and without prior application of a clay grout. The test samples were produced also differently, by cutting while fresh, cutting after hardening and directly sample moulding. Tests were performed in two different relative humidity environments: 65% and 95%. The results are compared, evaluating the influence of the different parameters, and with results of other plasters. The earth plaster presented a good performance regarding adhesion on both substrates studied, being advantageous the preparation of the support with a clay grout. The cutting procedure of the samples influences the test results being the fresh mortar cut less harmful. The relative humidity increment has a negative effect on the adhesion capacity but even a high percentage does not compromise the stability of the plaster. The shear test proved to be a valid instrument when specific pull-off equipment is not available.

Introduction

In recent years earthen mortars and plasters have been calling the attention of the building community not only because they are ecological, reversible, compatible with historic masonries such as earth-based or rubble stone, but also because they can be efficient even when applied on current contemporary masonries [1, 2, 3]. Particularly, the contribution earthen plasters can give to relative humidity indoor equilibrium, based on the high hygroscopicity of clays, classifies them as passive technologies to achieve indoor comfort [4]. Nevertheless, the knowledge on the application of earthen plasters was almost lost in developed countries and is being re-gained in the last years [5,6].

One of the aspects that is fundamental for plastering earthen or mineral binder-based mortars is the adhesive strength on substrates, which is the capacity of the plaster to resist to normal and tangential tensions at the interface with the support. It depends mainly on the following physical phenomena: the matrix mortar penetration in the support pores and the surface connections anchoring the mortar to support roughness. The higher the roughness, the higher the contact area. Therefore, the porous structure of the support and its roughness are fundamental to adhesion. Nevertheless, the porosity of the support should not be too high to avoid excessive mortar matrix absorption that can weaken the layer of mortar in direct contact with the support (Figure 1).

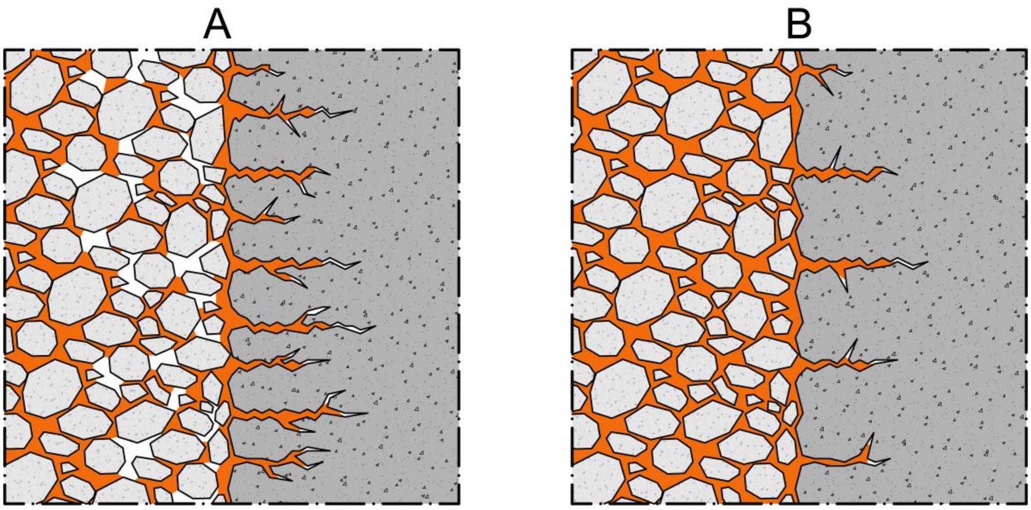

Figure 1. Schematic representation of a mortar applied to a more (A) or less porous (B) support

Furthermore, as a complex mechanism, adhesion is also affected by in service factors [7], such as the type of support where the mortar is applied and their cleanliness or preparation, the mortar formulation and thickness of application, the hygrothermal conditions when the application is performed.

A traditional way of improving the adhesion of a plaster is to perform support preparation with the application of a grout or slurry that can increase roughness of too smooth surfaces and control mortar matrix absorption, acting as a primer to the plaster system application. For earthen plasters Deliniere et al [5] applied earthen plasters on a concrete support with and without the previous application of a water-clay slurry or grout (*barbotine*) by brush. In this study the grout application increased the adhesive strength results by pull-off test based on EN 1015-12 [8] and all the mortars surpassed the minimal limit of DIN 18947 [9].

For earth mortars the bonding depends mainly on the clay content. An earth plaster with very high clay content will crack and loose adhesion, while a plaster with a too low clay content will have a weak bond to the support [10]. In fact, the thickness of a plaster (and of each plaster layer) is also important because it is directly proportional to the adhesive action due to gravity.

The influence of hygrothermal conditions on the adhesion of an earth plaster is due to the high hygroscopicity of clays. When in contact with liquid water, clays acquire plastic properties which, from a certain extent, may compromise the plaster hardened state stability. For earth mortars the DIN 18947 [9] defines that the test can only be performed after the specimens are at least 7 days at 23±2 ^{o}C and 50±5 % relative humidity (RH).

The DIN 18947 [9] defines the assessment of adhesive strength of earth plasters to a support based on the EN 1015-12 [8] test procedure. However, there are problems to assess the adhesion by EN 1015-12 standard [8] test procedure even for air lime-based plasters and renders [11]. In fact this test is generally performed on plaster samples that are cut on *in situ* plasters or, in laboratory, on a plaster specimen applied on a support. In the laboratory, that support can be a concrete small slab, a brick or a ceramic tile. The cut of the sample is generally performed when the plaster specimen is hardened; that is always the case *in situ*. The cut should penetrate few millimetres on the support itself. After the cut, a metallic device with circular area (Figure 2A) is glued to the sample ensuring complete contact. The pull-off can be applied through it. The pull-off can be applied by a pull-off test equipment (Figure 2B) or even by a tensile test equipment. The rupture can occur: in the thickness of the sample - cohesive rupture (Figure 2C) - meaning that the adhesive strength is higher than the registered value; by the contact surface between the mortar and the support - adhesive rupture - registering the adhesive strength; by the support, meaning that the adhesive strength is higher than the registered value [8]. In this last case it also means that the plaster is stronger than the support, what can be a problem for architectural heritage conservation, considering that the plaster should be there to protect the support and not imposing extra tensions. Both the type of rupture and the adhesive strength, that is obtained by the quotient of the maximum force and the contact area, are registered.

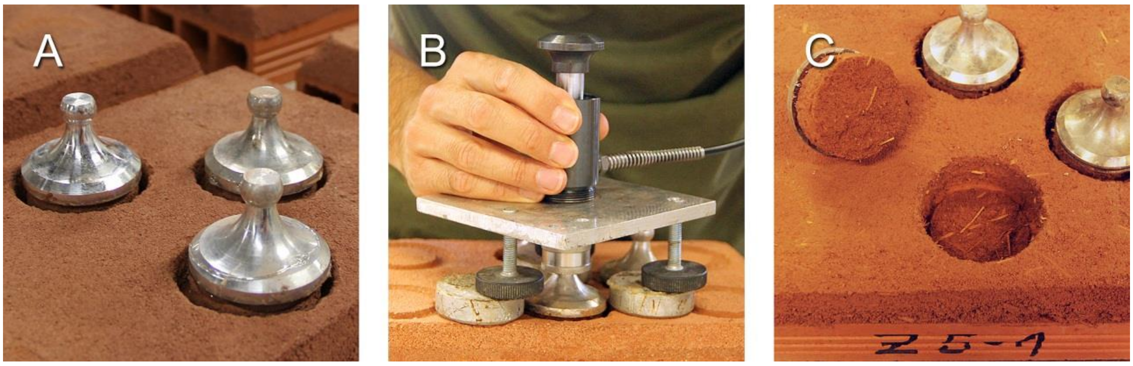

Figure 2. Pull-off test: A - Metallic devices glued to the plaster specimens; B – Pull-off equipment perpendicular to the specimen being tested; C – specimen after cohesive rupture

For low strength plastering mortars the samples cutting process, inflicting some level of vibration, can damage the sample and turn it unusable. Therefore, in laboratory sometimes the cut is performed manually while the plastering mortar applied on the support is still fresh [8], without cutting the support. The difference is that, in this case, as the cut does not penetrate in the support, the rupture hardly will happens in that element, therefore eventually misleading conclusion regarding absence of cohesive rupture.

The characterization of adhesive strength of plasters by a tensile test can be argued because the application of a force perpendicular to the support may not be the best way to simulate adhesive tension of that plaster. Delinière et al [5] suggest that a shear test should be more appropriate. Shear tests are not standardised and different studies used diverse equipment to perform it. Stolz and Masuero [12] used what they called an adhesive meter specifically developed. Hamard et al [10] assessed the adhesion of earthen plasters by a simple shear test that can be performed easily *in situ*. Vertical earth plaster samples with 50 mm x 40 mm x 20 mm are applied on a support or cut with those dimensions after drying. A simple device, as described in Hamard et al [10], is placed with good contact with the sample top and avoiding contact with the wall to reduce friction. The device is successively loaded with 250 g weigh with 10 s intervals. The total mass that produces the sample rupture from the support is registered. For masonry walls, there should be samples on the masonry units but also samples on both the masonry joints and units. Earth plaster samples on which rupture do not occur when loaded with a force of 20 N (approximately 2 kg) are considered adequate [10].

The DIN 18947 [9] considers the adhesive strength, together with the flexural and compressive strengths, to mechanically classify earth mortars (Table 1).

Table 1. Mechanical classes or earth plasters defined by DIN 18947 [9]

Mechanical class	Compressive str. [N/mm^2]	Flexural str. [N/mm^2]	Adhesive str. [N/mm^2]
SI	≥ 1.0	≥ 0.3	≥ 0.05
SII	≥ 1.5	≥ 0.7	≥ 0.10

Rohen and Ziegert [13] consider that earth plasters should present minimum adhesive strength of 0.03 N/mm^2 but that values of 0.15 N/mm^2 are common. In fact, Faria et al [6] for a ready-mixed earth plaster formulated with an illitic clay from Algarve Barrocal, Portugal, obtained adhesive strength of 0.15±0.03 N/mm^2.

Therefore, this study intends to give a contribution on how to assess adhesion of earthen plasters to a masonry, namely comparing the influence of tensile and shear testing procedures, on two different substrates - adobe and hollow fired clay bricks - , prepared differently, with application of a clay slurry previous to the plastering or just water spray, with the test samples produced differently, by cutting while fresh, cutting after hardening and directly sample moulding with aimed test dimensions, and in equilibrium on two different RH environments: 65% and 95%.

Materials, mortar and samples

The clayish earth was excavated in an Algarve Barrocal quarry, south Portugal. It was grinded to reduce clods and sieved to remove coarse particles. The earth used is composed by sand, silt and clay. The latter is mainly illitic and has been characterized by Lima et al. [4]. As the earth clay content is high, additional siliceous sand was used to prepare the earth mortar. The dry particle size distribution of the grinded earth and the sand, determined based on EN 1015-1 [14], are presented in Figure 3. The sand presents higher content of particles between 0.25 and 1 mm in comparison with the earth, that in turn presents a higher content on fines and a more homogeneous distribution of particles.

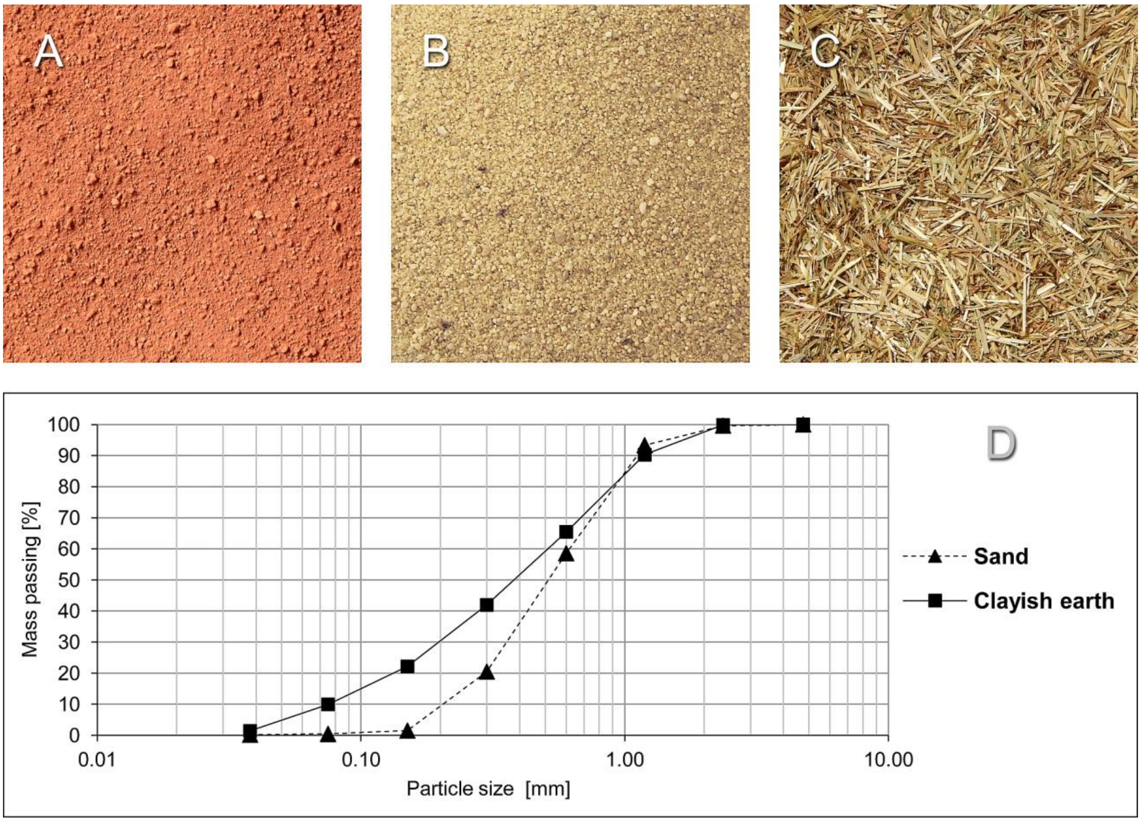

Figure 3. Clayish earth (A), sand (B), oat fibres (C) and dry particle size distribution of the sand and clayish earth (D) used in the mortar formulation.

Oat fibres were also used for the mortar formulation. The loose bulk density of all the materials was determined based on EN 1097-3 [15] (average and standard deviation of six tests) and is presented in Table 2.

Table 2. Loose bulk density of mortar materials and water absorption coefficient under low pressure of supports

	Loose bulk density [kg/m^3]			AC [kg/(m^2.min$^{0.5}$)]	
	Earth	Sand	Fibres	Brick	Adobe
Average	1317.0	1591.8	62.5	0.82	0.45
Stand. Dev.	1.8	0.6	4.9	0.06	0.08

It can be observed that the sand bulk density is higher than the one of the earth, which may be explained by lower content on silica grains of the latter, while the bulk density of the fibres is, as expected, very low. The high standard deviation of the fibres was justified by the fact that the test is performed without compaction and, therefore, the position of the fibres produces different voids. Santos et al. [16] also achieved a similar bulk density of 70 kg/m^3 for oat fibres.

The supports for the plaster were ceramic fired hollow brick, with 30 cm x 20 cm x 7 cm, and adobe, with 30 cm x 15 cm x 7 cm, representing a nowadays prevailing support and an earthen one. Both materials water absorption under low pressure was determined by Karsten tube test after 60 minutes, based on LNEC Fe Pa 39 [17] and EN 16302 [18], and results are presented in Table 2. Water absorption coefficient of the brick is higher in comparison with adobe.

The mortar was formulated with a volumetric proportion of 1:3 (clayish earth:sand) adding 5% (of total weight of earth and sand) of fibers. Based on the loose bulk density, it corresponds to 1:3.6:0.01 mass proportion of earth:sand:fibers. The mortar preparation was performed based on the DIN 18947 [9]. A previously defined amount of water of 12.8% (of total weight of earth and sand) that ensure good workability of the mortar [4] was placed in the mechanical mixer recipient and the solid components were added during the first 30 seconds of mixing. A mechanical mixing went on for 30 seconds and the mortar rested for 5 minutes, after which it was mechanical mixed again for 30 seconds more.

Prismatic samples with 40 mm x 40 mm x 160 mm were produced in metallic moulds, with two layers compacted in sequence. The excess of mortar was removed and the surface regularized.

Plaster samples with 2 cm thickness were produced over both brick and adobe surfaces, with 30 cm x 20 cm and 30 cm x 15 cm, respectively, after water spraying or the application with a brush of a clayish grout made with 1:1 mass proportion of the earth and water. The support materials were placed inside a frame mould with height 2 cm higher than the supports. To simulate and homogenize the mortar projection energy to the support, the mortar was dropped vertically from a height of 70 cm. The excess of mortar was removed and samples were regularized. In some cases the mortar did not plastered all the support but only the moulds of adhesion test specimens that were specifically placed on the support surface, depending on the test procedure (see test procedure for adhesion tests).

After moulded all the samples were kept for one month in a conditioned room at 23±2^{o}C and 65±5% RH before being tested.

Test procedures

General characterization of the mortar

The mortar was characterized for common properties both in the fresh and hardened state. In the fresh state flow table consistency was performed based on EN 1015-3 [19] and bulk density was assessed following EN 1015-6 [20].

In the hardened state the mortar was tested for bulk density by the geometrical methods defined by EN 1015-10/A1 [21] and for dynamic modulus of elasticity (Ed) based on EN 14146 [22] using a Zeus Resonance Meter ZMR 001, with its own software, that calculates Ed based on the geometry and mass of the sample, gravitational acceleration and longitudinal resonance frequency.

Based on EN 1015-11 [23] the flexural and compressive tests were performed with a Zwick/Rowell Z050 equipment, with load cells of 2 kN, a speed of 0.2 mm/min and a 3 point bending test for flexural, with 100 mm between the supports, and a 50 kN load cell, 0.7 mm/min speed and a compressive area of 40 mm x 40 mm for compression. Six samples were tested for each property.

Pull-off test

The pull-off test was performed based on EN 1015-12 [8] with the mortar samples in equilibrium at 65±5 % RH and 90±5 % RH, with previous sprayed water or clayish grout application and different specimen preparation. A PosiTest AT-M equipment, a pull-off equipment specific for low strength, was used with circular metallic pieces with 50 mm diameter. For the application of the circular pieces three different types of specimens were produced and tested: cylindrical specimens cut when the plaster sample on the support was hardened (hardened cut HC); cylindrical specimens cut with a metallic cylinder tube when the plaster sample was fresh (fresh cut FC) and cylindrical specimens that were directly moulded using a cylindrical plastic mould placed on the support instead of plastering the all support surface (direct moulding DM). The equipment was manually and slowly and gently operated so that the rupture occurred after 20-60 seconds. The adhesion strength was obtained dividing the rupture force by the contact area of the sample cut section, in N/mm^2. Nevertheless, the glued area is always measured and if the contact was not total, the real adhesive strength is corrected dividing the metallic piece area by the real contact area. The type of rupture is also registered. Results are an average of 5 tests.

Shear adhesion test

(2013 Results are an average of at least 5 tests.

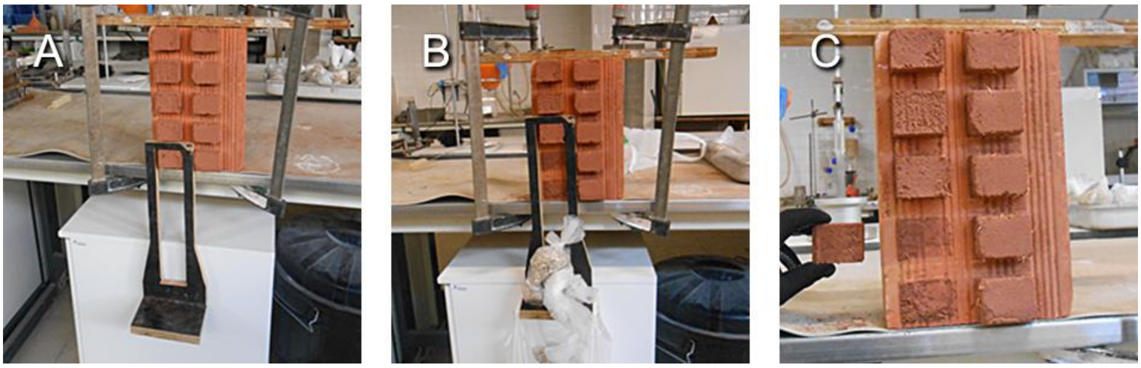

Figure 4. Shear adhesion test on moulded samples: (A) application load device on a sample; (B) successive 250 g loads applied on the device; (C) a moulded samples after rupture.

Results and discussion

Fresh and hardened state characterization of the mortar

Flow table consistency of the mortar was 176±1.5 mm. The result is within the range of 175±5 mm defined by DIN 18947 [9]. Fresh state bulk density had an average value of 2.06 kg/dm^3, which is higher than the minimal of 1,2 kg/dm^3 defined by DIN 18947 [9]. Nevertheless, the value is comparable with the ones of Delinière et al. [5] that for two ready-mixed mortars and three laboratory formulated ones presented results of 2.0-2.1 kg/dm^3. The results are also within the range of the ready-mixed earth plaster produced with an illitic earth from the same quarry tested by Faria et al. [6] that registered 2.03 kg/dm^3 and 2.11 kg/dm^3, respectively when the mortar was mixed on site and in the laboratory. Santos et al. [16] when testing a ready-mixed earth mortar and a formulated mortar with oat fibres obtained a similar bulk density of 2.00 kg/dm^3 as well as Gracía-Vera et al. [24] that registered 2.06 kg/dm^3 and 2.05 kg/dm^3 for two earthen plasters based in two different raw earths.

Hardened state bulk density (average and standard deviation) was 1.97±0.01 kg/dm^3. Based on DIN 18947 [9] the mortar is classified in class 2 (between 1.81 and 2.00 kg/dm^3). This result is similar to other studies. Delinière et al [5] for both ready-mixed and formulated earth mortars registered bulk densities of 1.7-1,8 kg/dm^3 , Lima and Faria [25] when testing illitic earth plasters achieved bulk densities between 1.91 kg/dm^{3,} 1.66 kg/dm^3, respectively without and with addition of oat or typha, while García-Vera et al. [24] achieved 1.83 kg/dm^3 and 1.81 kg/dm^{3,} respectively for red and yellow plasters, although with a much higher standard deviation. The bulk density of the present study mortar is also higher than the one of the ready-mixed mortar tested by Faria et al. [6] that registered 1.77 kg/dm^3 and the ready-mixed mortar and the oat fibres formulated mortar tested by Santos et al. [16] with 1.77 kg/dm^3 and 1.72 kg/dm^3, respectively.

Mortar dynamic elasticity modulus (Ed), flexural and compressive strengths results are presented in Table 3.

Table 3. Dynamic modulus of elasticity, flexural and compressive strength of mortar

Property	N/mm^2
Ed	4231±86
Flexural str.	0.24±0.02
Compressive str.	0.81±0.22

The flexural and compressive results are consistently lower in comparison to the ready-mixed earth mortar characterized by Faria et al. [6] produced with clayish earth from the same quarry, using similar test procedures, that registered 0.3 N/mm^2 and 1.1 N/mm^2, respectively. That was inverse to what was expected by the higher bulk density of the mortar tested in the present study. Nevertheless, Ed of the present study is higher than the one of Faria et al. [6], in agreement with that higher bulk density. Results of the present study are also lower than the ones of Delinière et al. [5] that achieved for five earth mortars flexural strength results of 0.49-0.69 N/mm^2 and for compressive strength between 1.3-2.1 N/mm^2. Nevertheless, the compressive and flexural strength are similar to the ones obtained by Lima et al. [4] for a mortar with clayish earth from the same quarry but without fibers, respectively 0.25 N/mm^2 and 0.88 N/mm^2, and respectively slightly lower than the results of Lima and Faria [25] for the same mortar but with addition of oat fibers, respectively 0.23 N/mm^2 and 0.67 N/mm^2, and slightly higher with addition of typha fiber-wool, that registered 0.31 N/mm^2 and 1.02 N/mm^2. When comparing with the present study, García-Vera et al. [24] testing both a red and a yellow earth mortars registered similar compressive strength results at 95% RH (0.8 N/mm^2 and 0.7 N/mm^2, respectively) and higher values when testing at 60% RH (1.0 N/mm^2 and 1.2 N/mm^2, respectively), showing that the ambiance test conditions may have a more significant influence than the type of earth.

Adhesion strength and type of rupture

Table 4 presents the type of rupture (adhesive or cohesive) and Table 5 presents the results of pull-off adhesion strength, while Table 6 presents the results of shear adhesion test.

Table 4. Pull-off adhesion rupture depending on the specimen preparation

Rupture	Fresh.cut	Hard.cut	Moulded	Global
	Number/%	Number/%	Number/%	Number/%
Cohesive	11/55	11/55	7/35	29/48
Adhesive	9/45	9/45	13/65	31/52
Total	20/100	20/100	20/100	60/100

Table 5. Pull-off adhesion of the mortar depending on the test procedure

Support	RH (%)	Preparation	Specimen	Adhesion str. (N/mm²)
Brick	65	Water	FC	0.13±0.01
			HC	0.09±0.01
			DM	0.14±0.02
		Grout	FC	0.13±0.00
			HC	0.12±0.01
			DM	0.14±0.02
	90	Water	HC	0.08±0.00
		Grout	HC	0.09±0.01
Adobe	65	Water	FC	0.13±0.01
			HC	0.11±0.01
			DM	0.15±0.01
		Grout	FC	0.14±0.01
			HC	0.13±0.01
			DM	0.15±0.01
	90	Water	HC	0.08±0.01
		Grout	HC	0.08±0.00

Notation: FC – fresh cut; HC – hardened cut; DM – direct moulding

Table 6. Shear adhesion of the mortar depending on the test procedure

Support	Preparation	Specimen	Adhesion str. (N/mm²)
Brick	Water	HC	0.04±0.01
		DM	0.04±0.00
	Grout	HC	0.05±0.00
		DM	0.04±0.00
Adobe	Water	HC	0.05±0.00
		DM	0.01±0.00
	Grout	HC	0.05±0.01
		DM	0.03±0.01

Notation: FC – fresh cut; HC – hardened cut; DM – direct moulding

The ready-mixed mortar tested by Faria et al. [6] presented a pull-off mainly adhesive rupture on samples applied on hollow brick after water spraying, cut after hardening and tested by the same type of equipment, with an adhesion strength of 0.15 N/mm^2 that is higher than the result of the present study. Nevertheless, using the same test procedure, Lima and Faria [25] registered adhesive strength of 0.09 N/mm^2 for the tested earth plaster with oat fibres addition, 0.11 N/mm^2 for similar plaster but with typha fibres and 0.07 N/mm^2 for the same plaster without fibres, results that are in the same range as the one registered in the present study for the same test conditions. Comparing the results of Delinière et al. [5] that applied the earth plasters on concrete panels and tested samples cut when the mortar was fresh, after water brushing (0.06-0.08 N/mm^2) and after applying a water-earth grout (0.11-0.14 N/mm^2), it can be seen that the influence of the preparation was more significant possibly due to the concrete substrate.

By the results obtained, it is not possible to mechanically classify the earth plaster based on the DIN 18947 [9] not because of the pull-off test results, that for a common RH environment of 65% present a minimum strength of 0.09 N/mm^2, but because the flexural and compressive strengths does not achieve the minimum values for class SI (Table1). Nevertheless, particularly the flexural strength is very close to the lower limit of SI class and, associated with the good values of adhesion, that is very positive for compatible plastering mortars.

The good results of the pull-off test may be partially justified by the equipment that was used – not a conventional pull-off for mortars but one more used for paint systems adhesion assessment. The adhesion was slightly higher to the adobe than to the brick. The testing at a high RH reduces adhesive strength but do not jeopardize adhesion of the plaster when comparing to the DIN 18947 [9] requirements. The previous application of the grout has a positive effect on adhesion in comparison with just the water spray, corroborating results of Delinière et al. [5]. The direct moulding of the samples (without cut) has also a positive effect on the adhesion and rupture is mainly adhesive, being the harden cut the sampling method with the more negative effect. Nevertheless, the cut methods have a higher percentage of cohesive rupture meaning that the adhesion to the support is higher than the registered values. Although the hardened cut method is the only one that can be performed to assess adhesion on existent plasters, the fresh cut method seems to be the easier to be performed in the laboratory and even in situ when new plasters or experimental samples of plasters are being applied.

The shear test presented significantly lower adhesion strength in comparison with the pull-off test. Nevertheless, in comparison with the adhesive strength obtained by Hamard et al. [10], that registered maximum values of 0.047 N/mm^2, 0.029 N/mm^2 and 0.028 N/mm^2 when testing three earthen plasters on a cob wall, it can be supposed that results obtained by the described shear test should not be quantitatively compared with the ones of pull-off. Therefore, more studies are needed using this test procedure so that more results can be compared.

Particular attention has to be taken on demoulding and cutting the samples of the dry mortar. Therefore, in following test campaigns, particularly when considering this shear test method, the moulding and the cutting must be optimized. For the time being the test is a good possibility for comparison between small samples for hypothesis of replacement plasters and renders tested on a real building, when a mechanical equipment is not available. It was easily performed on both brick and adobe supports and, as the pull-off test, the grout application has also positive effect on adhesion strength. In following experimental campaigns the test should be performed with the brick longest dimension oriented horizontally in order to assess the influence of the brick surface grooves, that in the present study were vertically oriented, therefore aligned with the shear force.

Conclusions

Results show that an earth plaster even without high compressive strength can perform well in terms of shrinkage and present efficient performance regarding adhesion on both substrates studied (brick and adobe). The preliminary preparation of the support with a clay grout/slurry is advantageous to adhesion performance, regardless of the testing methods. The cutting and moulding/demoulding procedure of the samples influences the test results. The relative humidity increment has a negative effect, decreasing the adhesion capacity, but even a high percentage does not compromise the stability of the plaster adhesion. The shear test proved to be a valid instrument mainly to compare experimental mortar samples that are being tested *in situ* for repair intervention when a pull-off device is not available. For testing existent plasters *in situ* the harden cut pull-off test is less destructive than the shear test (because the latter implies the removal of adjacent areas of the plaster sample) and is the only that can assess cohesive rupture by the support, assessing compatibility between the plaster and the support. For laboratory testing the pull-off test with previously fresh cut samples seems to be the most appropriate.

It is possible that similar conclusions can be enlarged to similar low strength plasters, such as air lime-based ones.

References

1. Melià P, Ruggieri G, Sabbadini S et al (2014) Environmental impacts of natural and conventional building materials: a case study on earth plasters. J Clean Prod 80:179-186

2. Faria P, Lima J (2018) Earthen plasters (in Portuguese). Argumentum, Lisbon

3. Santos T, Faria P, Silva V (2019) Can an earth plaster be efficient when applied on different masonries? J Build Eng 23:314-323

4. Lima J, Faria P, Santos Silva A (2016) Earthen plasters based on illitic soils from Barrocal region of Algarve: Contributions for building performance and sustainability. Key Eng Mat 678:64-77

5. Delinière R, Aubert JE, Rojat F et al (2014) Physical, mineralogical and mechanical characterization of ready-mixed clay plaster. Build Environ 80:11-17

6. Faria P, Santos T, Aubert JE (2016) Experimental characterization of an earth eco-efficient plastering mortar. J Mater Civil Eng 28(1):04015085

7. Matos Silva C, Flores-Colen I, Gaspar S (2013) Numerical analysis of renders' adhesion using an interface model. Constr Build Mater 38:292-305

8. EN 1015-12 (2016) Methods of test for mortar for masonry. Part 12: Determination of adhesive strength of hardened rendering and plastering mortars on substrates. CEN, Brussels

9. DIN 18947 (2013) Earth plasters – Terms and definitions, requirements, test methods (in German). DIN, Berlin

10. Hamard E, Morel JC, Salgado F et al (2013) A procedure to assess the suitability of plaster to protect vernacular earthen architecture. J Cult Herit 14(2):109-115

11. Airaghi C, Botteon D, Canziani G et al (2014) EN 1015-11 and EN 1015-12: Proposal to update procedures for lime products. 9th International Masonry Conference, Guimarães.

12. Stolz C, Masuero A (2012) Influence of the real contact area of rendering mortars on shear strength adhesion (in Portuguese). 4º Congresso Português de Argamassas e ETICS, Coimbra.

13. Röhlen E, Ziegert C (2011) Earth building practice. Beuth Verlag GmbH, Berlin

14. EN 1015-1 (1998) Methods of test for mortar for masonry. Part 1: Determination of particle size distribution (by sieve analysis). CEN, Brussels

15. EN 1097-3 (1998) Tests for mechanical and physical properties of aggregates. Part 3: Determination of loose bulk density and voids. CEN, Brussels.

16. Santos T, Nunes L, Faria P (2017) Production of eco-efficient earth-based plasters: Influence of composition on physical performance and bio-susceptibility. J Clean Prod 167:55-67

17. LNEC FE Pa 39 (2002) Wall coatings. Test of water absorption under low pressure (in Portuguese). LNEC, Lisbon

18. EN 16302 (2013) Conservation of cultural heritage. Test methods. Measurement of water absorption by pipe method. CEN, Brussels

19. EN 1015-3 (1999) Methods of test for mortar for masonry. Part 3: Determination of consistence of fresh mortar (by flow table). CEN, Brussels

20. EN 1015-6 (1999) Methods of test for mortar for masonry. Part 6: Determination of bulk density of fresh mortar. CEN, Brussels

21. EN 1015-10 (1999) Methods of test for mortar for masonry. Part 10: Determination of dry bulk density of hardened mortar /A1. CEN, Brussels

22. EN 14146 (2004) Natural stone test methods. Determination of the dynamic modulus of elasticity (by measuring the fundamental resonance frequency). CEN, Brussels

23. EN 1015-11 (1999) Methods of test for mortar for masonry. Part 11: Determination of flexural and compressive strength of hardened mortar. CEN, Brussels

24. García-Vera V, Lanzón M (2018) Physical-chemical study, characterisation and use of image analysis to assess the durability of earthen plasters exposed to rain water and acid rain. Constr Build Mater 187:708-717

25. Lima J, Faria P (2016) Eco-efficient earthen plasters. The influence of the addition of natural fibers. Natural Fibres: Advances in Science and Technology Towards Industrial Applications. From Science to Markets. R. Fangueiro, S. Rana (Eds.). Springer, RILEM Book Series 12:315-327

FARIA P., LIMA J., NABAIS J., SILVA V. (2019), Assessment of adhesive strength of an earth plaster on different substrates through different methods. HMC2019 - 5th Historic Mortars Conference, 19-21 June 2019, Pamplona. RILEM Proceeedings PRO 130, José Ignacio Álvarez, José María Fernández, Íñigo Navarro, Adrián Durán, Rafael Sirera (Eds.), ISBN: 978-2-35158-221-3, e-ISBN: 978-2-35158-222-0, 51-64.
https://www.rilem.net/publication/publication/494?id_papier=11341