Adhesion of Gypsum Plaster Coatings: Experimental Evaluation

A. C. Azevedo, J. M. P. Q. Delgado, T. H. C. Neves, and A. J. Costa e Silva

Abstract Nearly 95% of the Brazilian production of natural gypsum comes from the state of Pernambuco, from the Araripe Gypsum Center. Of the 95%, that is to say, of the 1.3 million ton/year production, 61% is allotted to the making of blocks and plates, 35% for coverings, 3% for ceramic moulding, and 1% for other uses. The Gypsum Center generates nearly 12,000 jobs directly and approximately 60,000 jobs indirectly, and has an annual invoicing of US$300M per annum. In civil construction, the use of gypsum increases continually, because plaster paste is seen by builders as a low cost, quality alternative material to be applied as coatings to internal walls. The reduced cost results in higher productivity on the part of the craftsperson due to the speed of application as well as providing a good final finish. Paint can be applied without needing to apply putty. Bases commonly used for these types of finishes are ceramic and concrete substrates. These materials are known for their excellent mechanical strength and low thermal conductivity. The superior surface quality on both sides of these materials makes them suitable for any thickness of plaster paste. This study evaluates experimentally the adhesion strength of coatings made with gypsum paste, considering different substrates and application heights. There are four types of blocks (ceramic and concrete, non-structural and structural blocks), two types of slice cutting (superficial and penetrating to the substrate) and three application heights (up to 0.6 m, between 0.6 and 1.2 m and above 1.2 m). The

A. C. Azevedo · J. M. P. Q. Delgado (✉)
Civil Engineering Department, Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal
e-mail: jdelgado@fe.up.pt

A. C. Azevedo
e-mail: antonio.costaazevedo@fe.up.pt

T. H. C. Neves
Instituto Federal de Ciências de Educação e Tecnologia de Pernambuco (IFPE), Brazil, USA
e-mail: engthcneves@gmail.com

A. J. Costa e Silva
Civil Engineering Department, Universidade Católica de Pernambuco, Brazil, USA
e-mail: angelo@tecomat.com.br

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results indicated the strong influence by the base and depth of cut on the adhesion, but there was no influence on adherence attributed to the height of application.

Keywords Gypsum paste · Ergonomics · Adhesion strength

1 Introduction

Adhesion is one of the most important properties for the performance of the compound, especially as it is responsible for securing the gypsum to the base over the years, including under any conditions to which it might be subjected. Adhesion can be used to describe the strength and the extent of contact between the mortar and the base (Argamassas 2010; Flores-Colen et al. 2009; Freitas et al. 2014; Melo et al. 2019).

Given this scenario, the contribution stemming from scientific and technological research is important in the elucidation of beliefs and factors that lead to empiricism. The application of knowledge acquired through research is capable of providing appropriate conditions for material development, as well as perfect construction techniques, contributing to the more significant rationalization of materials, productivity gains and, above all, a decrease in the incidence of pathological manifestations, as the potential is known, and the weaknesses of the system can be worked out (Scartezini 2002).

In this sense, this work is designed to provide an evaluation of the influences of two of the main types of bases (ceramic and concrete blocks, both structural and non-structural) based on the results obtained at different application heights of the gypsum plaster coating. For a more enriched discussion, the influence of some generating conditions on the overall behaviour will be evaluated, starting with the analysis of the depth of the cut used in the implementation of the test, as well as the ergonomics.

The construction industry is responsible for a high level of extraction of natural resources from the planet. Because of this, the emergence of new materials, as well as new construction systems, occur as a result of the need for more excellent production, in less time, with high quality and lower costs.

Gypsum plaster coatings, widely used as a protective layer for buildings and masonry work, are responsible for protection, impermeability, beautification, and user comfort. The lack or loss of adhesion of the coatings leads to economic losses and, especially, to diminished liability, directly interfering with the course of human life.

The application techniques of gypsum plaster, unlike cement mortars, are not done by roughcasting, but by compressing the paste into the base, with the aid of a trowel. Thus, this can imply an influence on the ergonomics as well as on the variations of the results found. This difference in the execution technique can also influence the final finish; therefore, we will evaluate the surface adhesion as well as deep adhesion.

There are currently several studies regarding the lack of adhesion in cementitious materials, which is something that does not occur in the area of gypsum coatings. Given this scenario, the study that guides the qualitative and quantitative analysis of coatings made with gypsum plaster becomes essential. Therefore, this work proposes to experimentally evaluate the adhesion capacity of layers made with gypsum plaster, considering different substrates and different heights of application.

The objective of this work is to evaluate, utilizing an experimental study, the influence of the base and the execution conditions on the adhesion strength of plaster paste coatings and acquire a better knowledge of the impact of base properties on the adhesion of plaster paste. This study also presents the effect of ergonomics from a comparative evaluation at different times of the test, as well as a comparative analysis the importance of the final finish, starting with surface and deep adhesion resistance of gypsum plaster.

2 Plasters in Civil Construction

Plaster stands out among the materials that have been growing in use over a long period. It can be considered the oldest binder known to man. Samples of this material have been found in abundance in constructions of ancient Egypt, the Keops Pyramid (2800 BC). It is also found among the ruins of the ninth millennium BC in Turkey and the ruins of the sixth millennium BC in Jericho (Baltar et al. 2005).

Also, according to these authors, the techniques for using this material, such as calcination, and its hydraulic properties were known to these ancient peoples. This knowledge spawned a variety of uses, from the making of decorative objects like statues to construction processes which are so well-known in today's engineering, such as wall coverings in the form of mortars and pastes. Lavoisier, in 1768, published the first scientific study of the phenomena related to plaster preparation. From 1885, the use of plaster in the construction industry has been stimulated by the discovery of a process which facilitates the delay in bonding time.

Plaster is present all over the world. Its largest producers and consumers are undoubtedly the countries of the American continent (see Table 1). Currently, the world's largest producers of gypsum are United States (17%), Iran (10%), Canada (8%), Mexico (7%) and Spain (6.8%), followed by other countries like Brazil, Chile, and Uruguay (Peres et al. 2008; Paula and Delgado 2017; Paula et al. 2017).

Gypsum exploration in Brazil is located, for all practice purposes, in the northeast (see Fig. 1). Currently, the largest producing locality is found in the Araripina micro-region in Pernambuco (comprised of the municipalities of Araripina, Trindade, Ipubi, Ouricuri, Bodocó, Morais and Exu) which generates more than 90% of the national production (Peres et al. 2008).

These authors also point out that the second most important locality in production is Grajaú, in Maranhão; the third is Codó, which is also in the municipality of Maranhão. Gypsum production exists in Nova Olinda, Ceará as well. Gypsum mining in Brazil is conducted in open-pit mines, with amphitheatre-shaped mine fronts and

Table 1 World gipsite production, in million tons

Country	2002	2003	2004	2005	2006	%PM
Australia	4268	4066	4325	3857	400	3.2
Germany	1761	1748	1579	1644	1650	1.3
Brazil	1633	1529	1472	1582	1600	1.3
Canada	8809	8378	9339	9400	9500	7.6
China	6850	6850	7000	7300	7500	6.0
Egypt	2000	2000	2000	2000	2000	1.6
U.S.A.	15700	16700	17200	21100	21100	16.9
Spain	11218	11500	12534	13000	13200	10.6
France	4900	5600	5700	4902	4800	3.9
Total (09)					61750	52.4
Worldwide total					125000	100

Fig. 1 Araripe plasterboard pole

ore benches ranging in thickness of around 15 m. Despite having increased in recent years, the per capita consumption of plaster in Brazil is quite low when compared to other South American countries (see Table 2), which is a promising indicator of potential market growth in the country in the next few years.

The state of Pernambuco, which has abundant gypsum reserves in the Sertão do Araripe region, encompassing the municipalities of Araripina, Bodocó, Ipubi, Ouricuri, and Trindade, is responsible for 95% of Brazilian production. Araripe

Table 2 Annual consumption in Chile, Argentina and Brazil

Country	Annual consumption (kg/hab.)
Chile	41
Argentina	21
Brazil	9.3

reserves are considered to contain the best quality ore in the world and have excellent mining conditions (Baltar et al. 2005)

According to information from the Sindusgesso (Union of Extraction and Processing Industries of Gypsum, Limestone, Gypsum Derivatives and Non-Metallic Minerals of the State of Pernambuco), the Pernambuco Gypsum Center contains 18 active mines, 69 industrial calcination units, and 250 precast industries, providing about 12,000 direct jobs and about 60,000 indirect jobs (Luz et al. 2001). The production of Gypsum Pole, in 2001, was 1.8 million ton/year, of which about 1.3 million of the manufacturing of plaster, about 500 thousand tons, is used in the production of cement (Luz et al. 2001).

Construction plaster is a powder material obtained by gypsum calcination and is composed of hydrated calcium sulphate, with basanite as its main component. The presence of anhydrite, gypsum, and aggregate impurities are also detected (Lyra 2002; Nita et al. 2004).

The production of natural plaster takes place basically in four stages (see Figs. 2 and 3): gypsum extraction, calcination preparation, calcination, and selection. Gypsum is a sedimentary rock which contains gypsum, anhydride, and some

Fig. 2 Gypsum, plaster raw material

Fig. 3 Casting powder obtained by calcination

impurities, usually mineral clay, calcite, dolomite, and organic materials (Barbosa et al. 2014).

Gypsum is a soft, compact, poorly soluble mineral, which is the primary material for the manufacturing of plaster. After extraction, gypsum undergoes some processing to suit the type of furnace where it will later be calcined. The processing stages are as follows: crushing, coarse grinding, stockpiling, drying, fine grinding, and packaging.

Calcination is the thermal process by which gypsum is dehydrated. The material is calcined at a temperature range of 140–160 °C, so that 75% of the crystalized water is removed from the structure to obtain the hemihydrate (Barbosa et al. 2014).

Calcination may be performed by dry or wet methods. If the gypsum is dry calcined under atmospheric or low pressure, beta hemihydrate is obtained. If calcination occurs under saturated water vapour pressure, alpha hemihydrate is obtained. The alpha plaster, due to its production process, is used for high-end applications (hospital plaster) and consequently is sold at higher prices. Beta plaster, with lower production cost, predominates in national construction plaster (Barbosa et al. 2014).

2.1 Concept of Adherence

The performance of plaster coatings is directly related to adherence and durability, as well as to other properties. Thus, regardless of the proportion of the plaster and the quality of the materials employed, it is imperative that optimum conditions of coating adherence at the base exist.

A concern for improved knowledge of the properties and phenomena that affect the detachment of the coatings can help avoid the disagreeable experience involved in reworking, dangerous accidents, and user dissatisfaction, as well as repair costs.

In buildings, one of the main reasons for coating mortar failure is related to the loss or lack of adhesion to the substrate. Thus, mortar's ability to achieve a complete, durable, and lasting adhesion to the base is perhaps the most critical property concerning the behaviour of said coating (Carasek 2007; Ioppi 1995).

Hardened coating adhesion is conceptualized as the "property of the coating to withstand normal or tangential stresses at the interface surface with the substrate" (Ioppi 1995).

2.2 Plaster/Substrate Adhesion Mechanism

In the case of plaster coatings, the term adhesion is used to describe the strength and extent of contact between the plaster and a porous base. This base, the substrate, is usually a type of masonry, which may be ceramic bricks, blocks, concrete blocks, structural concrete bricks, structural ceramic bricks, etc., as well as their in situ concrete structure mould.

Didactically, it can be said that adhesion derives from the combination of three properties of the mortar/substrate interface: the tensile bond strength, the shear bond strength, and the bond length, which is the ratio between the precise contact area and the total possible area to be joined (Carasek et al. 2001, 2011).

In addition to the need for strength and sufficient adhesion surface, the durability of the bond is essential for strong adhesion, which begins with the initial hardening of the mortar and continues throughout the service life of the coating. If cracks occur during or after the hardening of the mortar, adherence may be compromised (Carasek et al. 2001, 2011).

The adhesion of the hardened mortar to the substrate is essentially a mechanical phenomenon, basically due to the penetration of the binder paste or the mortar itself into the pores or between the roughnesses of the application base. When the mortar in the plastic state comes into contact with the absorbent surface of the substrate, part of the kneading water, which carries with it the binder components in dissolution or colloidal state, penetrates through the pores and cavities of this substrate (Carasek et al. 2001, 2011).

2.2.1 Influence of Base (Substrate) on Adhesion

Base adhesion is the foundation for the application of the coating layers. The most frequently used are masonry bases and concrete structure. The substrate, especially those that are not roughcast applied, can have a significant influence on the final quality of the coating due to the diversity of characteristics and texture: absorbent, waterproof, smooth, rough, rigid, and deformable (Santos 2008).

NBR 7200 (1998) specifies that the coating bases must meet the flatness, plumb and levelling requirements set in masonry and concrete structure standards. When the base is composed of different materials and is subjected to forces that generate considerable differential deformations—overhangs, eaves, and last floors, for example—a metallic, plastic or other similar substance should be used to join these materials, creating an area capable of withstanding movement. Alternatively, a joint may be required that separates the coating which spans over the two different elements, allowing each part to move separately.

Analysing the results presented in this work together with NBR 13749 (2013), which prescribes the tensile bond strength limits for plaster and monolayer coats, we can verify that the coatings applied to the substrates of rough or chipped ceramic brick, solid brick with and without splatter cast and rough concrete blocks met the requirements for application of internal wall and ceiling coatings, appropriate for the option of a painted finish or plaster base on interior surfaces, as they presented tensile strengths above 0.20 MPa as required by the standard.

2.2.2 Requirements and Performance Criteria

The dimensions of the blocks, the shape of the cross-section, the presence of coatings, the height/thickness of the wall, the characteristics of the mortar, the rigidity of the structure, and the presence of door and window gaps significantly influence the performance of the masonry (Costa e Silva et al. 2017).

In the case of walls, the compressive strength of the blocks, in addition to being a general indicator of their quality, will have a direct influence on the shear and compressive strength of walls required by imposed deformations of the structure. Blocks with a minimum compressive strength of 1.5 MPa can be used in light masonry filling walls. If the walls are subjected to imposed deformations or more significant occupancy loads, the blocks with a minimum resistance of 3 MPa should be chosen. The deformability of non-load bearning masonry of hollow ceramic blocks can be evaluated based on the values of their deformation module (Costa e Silva et al. 2017).

In special situations, such as buildings with more than 20 floors, longer walls, and walls with a considerable height (over 3 m), masonry must have adequate resistance to lateral loads, particularly those imposed by the wind. In this case, the bending moment acting on the wall shall be calculated based on the dynamic load, the wall dimensions, and its bonding conditions. At the same time, the dynamic stress shall not exceed the allowable masonry stress required for flexural traction. For masonry with fully filled lashing joints (horizontal joints and vertical joints) laid with mortars of compressive strength greater than or equal to 5 MPa (Costa e Silva et al. 2017).

Non-structural Ceramic Substrates

Hollow components, with prismatic holes perpendicular to the faces on which they are located, incorporating non-structural masonry interspersed in the spans of reinforced

Fig. 4 Structural blocks factory

concrete structures, steel or other materials are generally employed with the holes arranged horizontally and should resist only their weight and small occupancy loads.

Structural Ceramic Substrates

Hollow components, with prismatic holes perpendicular to the faces on which they are located, which incorporate masonry that makes up the sturdy framework of the construction, and are usually applied with the holes arranged vertically, can also be used in non-load bearing masonry.

Non-structural Concrete Substrates

Non-structural blocks and structural blocks made of concrete are apparently physically identical. However, structural blocks have thicker walls, which gives it increased resistance to compressive stresses and can, therefore, be used to support building constructions.

Structural Concrete Substrates

Structural concrete substrates have good compressive strength and range between the minimum 4.5 MPa required by current standards and 16 MPa. This higher strength is only available from some manufacturers, and this type of block weighs more. Compared to other units, the concrete block wall (see Fig. 4) performs the structure and closing functions by eliminating columns and beams and reduces the use of reinforcement and cement forms. These are below the required 0.30 MPa.

2.3 Properties of Fresh Mortar

Initial adherence is the ability of the mortar to anchor itself to the base surface by penetration of the paste into the pores, recesses, and protrusions followed by the gradual hardening of the substance (Santos 2008).

The initial adherence, also called "tackiness," is the ability of the fresh mortar to initially bond to a base. It is directly related to the rheological characteristics of the binder paste, precisely its surface tension. Reducing the surface tension of the paste favours substrate "wetting" diminishing the contact angle between the surfaces and the implementation of adhesion. This phenomenon provides a more significant physical contact of the adhesive with the aggregate grains as well as with its base, thus improving adherence (Carasek 2007).

2.4 Properties of Mortar in a Hardened State

Adhesion is a property that the coating possesses in order to remain attached to the substrate through resistance to the standard and tangential stresses that arise at the base/coating interface. It is the result of tensile bond strength, shear bond strength, and mortar bond length. Adherence depends on the properties of the mortar in the fresh state, the coating performance procedures, the nature and characteristics of the base and the cleanliness of the surface. The pull-off test can be used to measure the tensile strength of the coating (Maciel et al. 1998).

The adhesion of the hardened mortar to the substrate is an inherently mechanical phenomenon due basically to the penetration of the binder or the mortar itself into the pores or into the roughness of the base to which it is applied. When the mortar in the plastic state comes into contact with the absorbent surface of the substrate, part of the kneading water, which contains the binder components in dissolution or colloidal state, penetrates through the pores and cavities of the substrate. Inside the pores there a phenomenon of precipitation occurs between the hydration products of cement and lime, and after some time, this initial precipitous intra-capillary action exerts an anchoring effect of the mortar to the base (Carasek 2007).

3 Experimental Campaign: Materials and Methods

3.1 Experimental Planning

The experiment was carried out from direct tensile bond strength tests performed on plaster pastes applied to ceramic and concrete, both structural and non-structural blocks (Naderi 2005). For improved visualization of these elements, the dependent and independent variables used are shown in Table 3.

In each of these bases, tests were performed on 120 samples, totalling 480 adherence tests, all performed at the age of 28 days. The choice of concentrating the tests only at one age was due to the preference for a more significant number of samples per study variable. The same stonemason raised the four (4) panels. These were divided into four bases with dimensions 1.50 m (width) × 1.80 m (height) and were constructed of the different aforementioned compositions. These were kept in a covered area of the Construction Materials Laboratory of the Catholic University of Pernambuco throughout the experiment. Industrialized block laying mortar was used for the raising of the walls, which the manufacturer indicated was a mortar suitable for multiple uses, using the mixture specified on the bag.

Seven days after having laid the blocks, measurements using *taliscas* was carried out in order to ensure uniformity of mortar thickness, set at 20 mm, followed by the application of plaster paste. For this step, the conventional application technique was used for this type of coating, which consists of manual compression of the paste on the base, with the aid of PVC trowel, and "slow" plaster, suitable for indoor use. The amount of water adopted was that indicated by the product supplier on the bag, and the mixing was done manually, with the craftsperson's trowel. For better orientation and understanding of the results, study families will be identified as described in Table 3.

On each of these bases, 120 samples were tested, totalling 480 adherence tests, all performed at 28 days of age. The choice of concentrating the tests only at one age was due to the preference for a more significant number of samples per study variable (see Fig. 5).

The four (4) panels were raised by the same stonemason and were divided into four bases of the following dimensions: 1.50 × 1.80 m^2 made of the different aforementioned materials, being exposed in an outside area of the Construction Materials

Table 3 Dependent and independent variables used in the study

Dependent variables		Independent variables	
Component	*Use*	*Test height*	*Cut profundity*
Ceramic brick (Tc)	Structural (E)	0–60 cm (A1)	Superficial (S)
Concrete block (Bc)	Non-structural (V)	60–120 cm (A2)	Profound (P)
		120–180 cm (A3)	
Example: Non-load bearing ceramic brick with a height from 0 to 60 cm and deep cut—TCVA1P			

Fig. 5 General overview of the bases

Laboratory of the Catholic University of Pernambuco. For the elevation of the walls, industrialized block laying mortar was used, which the manufacturer indicated was a mortar suitable for multiple uses.

Seven days after laying the blocks, an initial plumb line was applied in order to ensure uniformity of the thickness of the mortar, established at 2 (two) centimetres, followed by the application of plaster paste. For this step, the conventional application technique for this type of coating was used, which consists of manual compression of the compound on the base, with the help of PVC trowel, and "slow" plaster, suitable for indoor use. The amount of water adopted was that indicated by the product supplier on the contents bag, and mixing was done manually with the craftsperson's trowel.

Before the application of the coating, no preparation of the base was performed except a surface brushing. All steps of the plaster paste execution were performed by the same stonemason in order to reduce operator influence on the results found (see Fig. 6).

3.2 Materials Used

The materials used in the experimental study performed in this dissertation, as well as their characteristics, are identified in this section. These materials are plaster, ceramic brick, structural ceramic brick, concrete block and structural concrete block, as detailed below.

Fig. 6 Structural block concrete with gypsum coating

Table 4 Results of the gypsum plaster characterization test

Tests		Results
Normal consistency		29.00 (a/g: 0.54)
Net content		14.20
Sieve size	Sieve 0.840 mm	0
	Sieve 0.420 mm	0.3
	Sieve 0.210 mm	6.98
	Sieve 0.840 mm	17.45
	Sieve 0.105 mm	75.27
Unit mass (g)		719.85
Fineness module		0.32 (thin plaster)
Compressive strength (MPa)		12.25
Catch time	Initial	00:26:38
	Final	00:48:10

3.2.1 Coating Plaster

Plaster was used for the manual coating, a material which is readily available in the region. Table 4 presents information concerning the tests of the physical and chemical characteristics of the product, involving standards and test methods.

3.2.2 Blocks

Ceramic and concrete, non-structural and structural blocks (see Fig. 7) were used in the experiments, all characterized by total water absorption, compressive strength, and dimension determination (see Table 5).

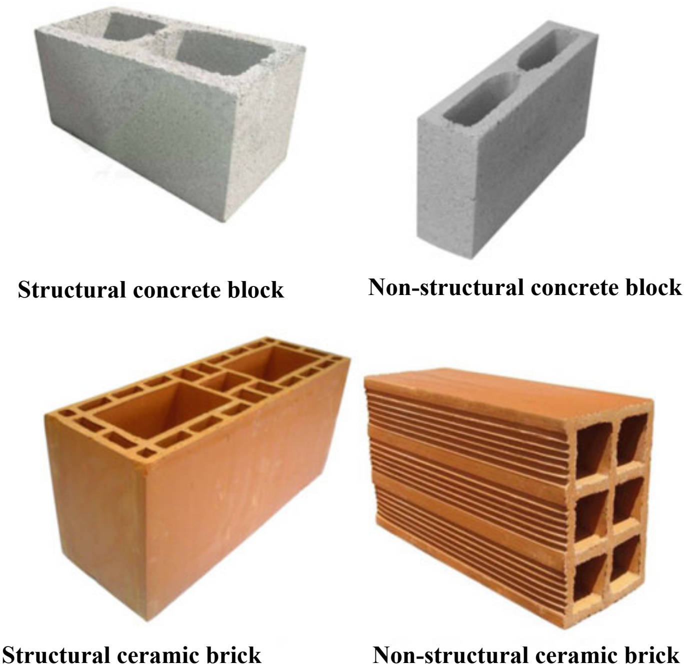

Fig. 7 Blocks used in the experimental campaign

Table 5 Results of the base characterization test

Characteristics	Standard	Ceramic bricks		Concrete blocks	
		Non-struct.	Structural	Non-struct.	Structural
Total water absorption (%)	NBR 7184 (1992)	18	12.5	8	6.5
Compressive strength (MPa)	NBR 6461 (2005)	1.2	2.7	3.4	6.6
Dimensions L × C × A (cm)	–	(9 × 19 × 19)	(14 × 39 × 19)	(19 × 19 × 19)	(9 × 39 × 19)

3.3 Experiment Description

For this experiment, masonry panels were prepared with ceramic and concrete blocks (non-structural and structural), coated with plaster paste. Tensile bond strength tests followed the procedure described in NBR13528 (NBR 1352), with 120 samples per substrate, totalling 480 tests. Initially, each base was divided into three heights (as sketched in Fig. 8), from 0 to 0.6 m; from 0.6 to 1.2 m and from 1.2 to 1.8 m. By

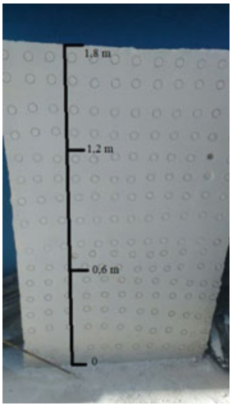

Fig. 8 Division of heights tested

separating the panels in this way, it was possible to verify the influence of ergonomics utilizing a comparative evaluation.

A Bosch GSB-13RE impact drill was used to perform the cuts (see Fig. 9), together with a 53 mm internal diameter diamond cup saw, cutting the coating through to the substrate. After removing the dust, a metal lining was attached to the specimen produced by the cut to facilitate equipment attachment. Metal lining fixation was done by bonding with epoxy adhesive 24 h before the test.

For the blocks, the test was carried out precisely on the surface, bearing in mind that each wall had one hundred and twenty specimens, sixty with cuts to the substrate and the other sixty with superficial cuts, as shown in Fig. 10.

For the performance of the bond strength test, an Alfa Instruments brand force transducer (see Fig. 11), model Z2T, nominal range 2000 kgf was used; and Alfa Instruments brand digital associated electronic instrumentation, model 3105C, serial

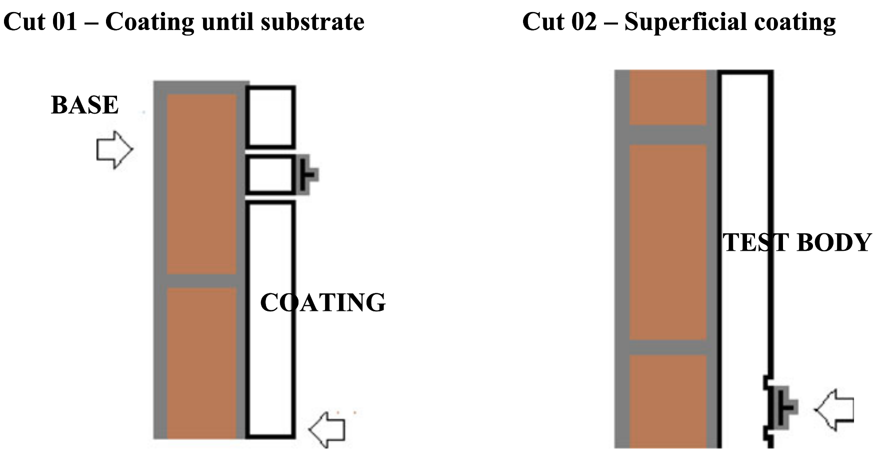

Fig. 9 Types of coating cuts

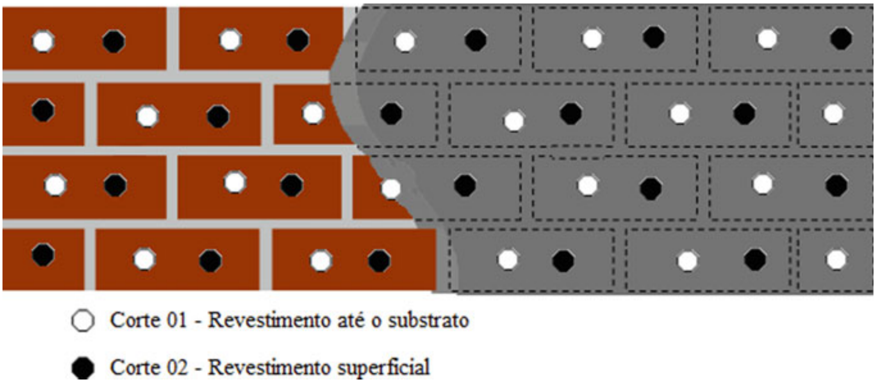

Fig. 10 Possible locations for determining tensile strength

Fig. 11 Digital equipment used in experimental set-up

number 100BC9, five-digit nominal range and 1 point. This equipment measures the tensile stress through a load cell, which records the tensile stress at break. The traction stress is applied by the use of a manual device with operator-controlled speed.

For bonding the metal parts required for the adhesion test, the panels were divided into 3 different heights, to allow for the evaluation of the influence of ergonomics, with cuts being made to avoid coinciding with the horizontal joints of the panels, thus avoiding the impact of these elements on adherence. The depth of 20 mm of the cut was controlled by a mark made on the cup itself, while in the case of the superficial evaluation, the metal linings were bonded directly to the paste, without delimitation

Fig. 12 Cut of the coating using a cup saw

Fig. 13 Structural concrete block with the coating all cut

by cut, as recommended by NBR 13755 (2017) for this type of assessment (see Figs. 12, 13 and 14).

4 Results and Discussion

This section presents the results obtained in the experimental program, which are the foundation for the discussion based on initial expectations, previous research, and existing literature. A statistical analysis (ANOVA) was performed, allowing for a more detailed analysis of the values presented, with a 95% confidence level.

Fig. 14 Specimens for testing

To facilitate a better understanding, since there are many variables involved in the study, the results will be presented in a scaled manner, from macro analysis to more detailed discussions of influential factors.

Figures 15, 16, 17 and 18 show the results of the underlying statistical analysis performed with the tensile strength values obtained from the coating bases under study. After the calculation of the bond strengths, the existence of spurious values was statistically verified, and these were eliminated from the mean calculation. The individual results, together with the respective cut types and heights tested, are compiled in Annexes I, J, L, and M.

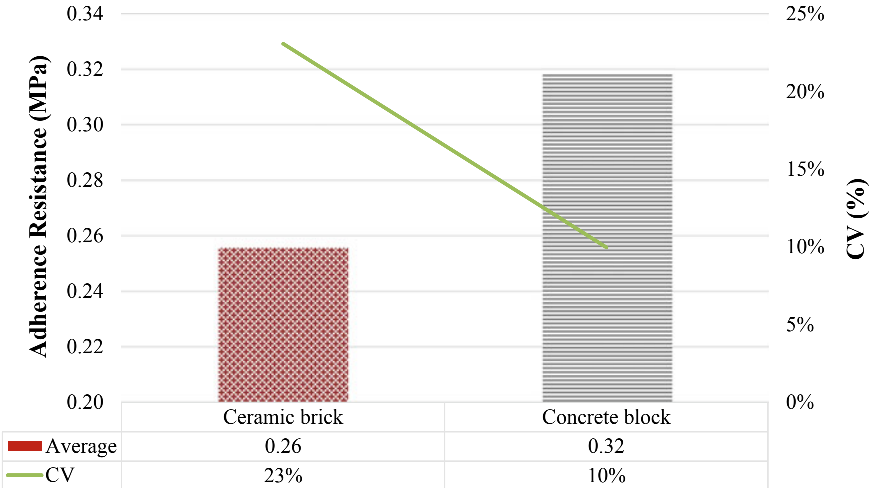

Fig. 15 Overall results of the 480 samples tested

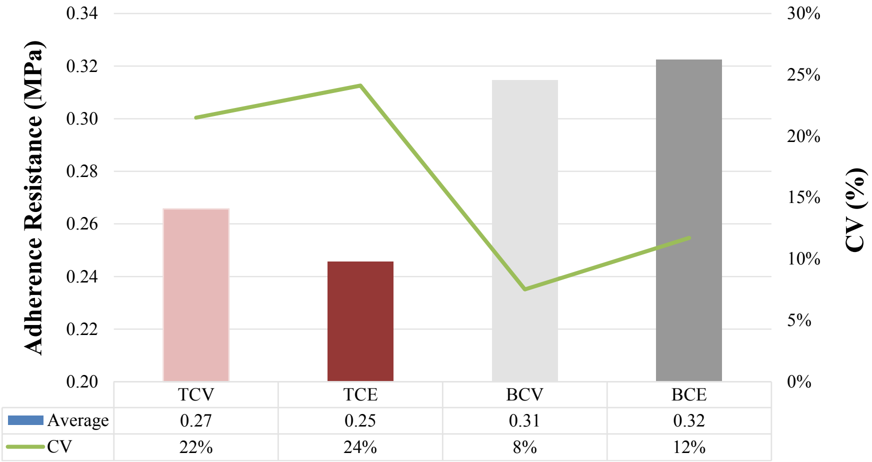

Fig. 16 Comparative results of the different bases

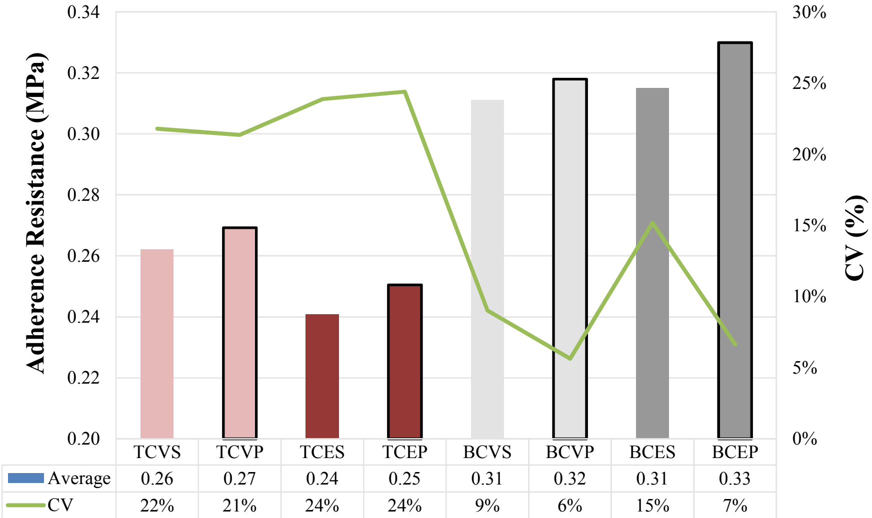

Fig. 17 Adhesion results with different bases and depth of cut

4.1 Base Type Influence

Figures 15 and 16 show the values found in the 480 samples tested separated according to the type of component used in the base. As can be observed, the adherence values found in the samples tested on concrete blocks were higher than those obtained in the case of ceramic brick bases, a behavioural difference considered significant by statistical analysis ($F_{calculated} = 385 > F_{critical} = 3.86$).

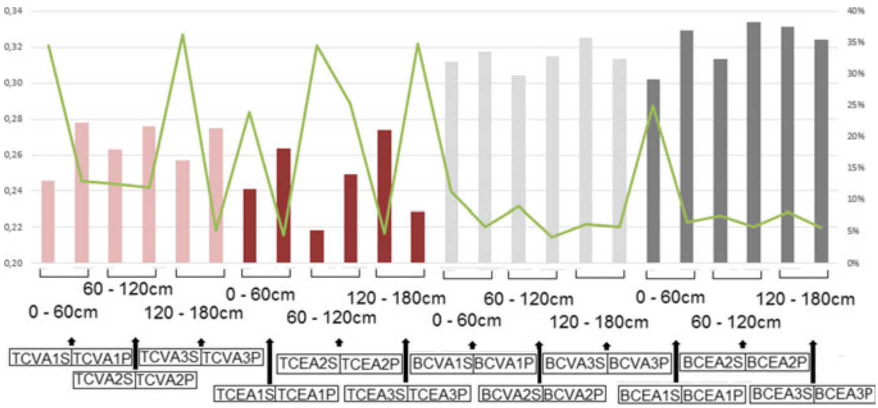

Fig. 18 Adherence results with different types of height

The better overall mechanical capacity between these bases can be credited to the higher roughness found in the concrete blocks, which helps in the macro anchoring of the plaster to the base while decreasing the contact area deficiencies. As for the coefficients of variation, higher values were found for the ceramic bricks, probably due to the naturally more significant heterogeneity of the manufacturing process of this type of component. It is crucial to keep in mind that the data analysed are from a set of 480 test samples, which corresponds to a number considered representative of the tests.

In this graph, each bar corresponds to a group of 120 samples and, in the case of ceramic bricks; a reduction in values can be observed when the tests were performed on structural components. For the ceramic blocks, an increase was observed when the test was performed with the structural elements. It is noteworthy that, in both cases, despite the close proximity between the absolute mean values, both are considered different by the analysis of variance at 95% (ceramic bricks: Calculated = 8.42 > Critical = 3.88; concrete blocks: Calculated = 12.01 > Critical = 3.88).

The difference in results between these bases can be credited to the increased roughness found in the concrete blocks, which helps in the macro anchoring of the plaster to the base and decreases the contact area deficiencies. It is crucial to keep in mind that in the case of concrete blocks, there was no significant difference observed whether they were structural or non-structural, unlike ceramic bricks, probably due to the naturally increased roughness of the concrete blocks.

In general, it is worth highlighting the predominantly adhesive rupture type in the samples (among those tested with paste cutting), especially in the bond between the paste and the base, which reinforces its influence on the adherence of the system. As for the coefficients of variation, higher values were found for the ceramic bricks, probably due to the naturally more significant heterogeneity of the manufacturing process of this type of component. It is important to be in mind that the data analysed are from a set of 480 test samples, which corresponds to a number considered representative of the tests.

4.2 Cut Profundity Influence

Figures 17 and 18 present the values found in the tested samples, separated according to the base type and profundity of the cut. The results showed a slight loss of adhesion resistance in the tested samples without making the cuts, which is, evaluating only the superficial layer, regardless of the base. This behaviour can be explained by the exposure of this surface layer after its execution, especially the presence of natural moisture, which tends to reduce the mechanical resistance of the gypsum plaster. Table 6 presents a summary of all rupture results obtained.

Table 6 Summary of rupture results

Rupture form (%)					
Coating age: 28 days					
	A	B	C	D	E
Panel 01: Non-structural ceramic brick					
Cut 01	29.83	27.83	39.67	0.00	0.00
Cut 02	00.00	29.75	66.67	0.00	0.00
Average	14.92	28.79	53.17	0.00	0.00
Panel 02: Structural ceramic brick					
Cut 01	29.25	24.00	41.75	0.00	0.00
Cut 02	00.00	23.42	71.58	0.00	0.00
Average	14.63	23.71	56.67	0.00	0.00
Panel 03: Non-structural concrete block					
Cut 01	31.25	22.42	47.33	0.00	0.00
Cut 02	00.00	20.33	79.67	0.00	0.00
Average	14.63	23.71	56.67	0.00	0.00
Panel 04: Structural concrete block					
Cut 01	32.83	17.42	49.75	0.00	0.00
Cut 02	00.00	19.82	79.42	0.00	0.00
Average	16.42	18.17	64.58	0.00	0.00
Legend of rupture type				Legend of cut type	
Type A—Substrate rupture				Cut 01—Coating to substrate	
Type B—Rupture in substrate/mortar interface				Cut 02—Surface finish	
Type C—Mortar rupture					
Type D—Tear/glue interface rupture					
Type E—Glue/insert interface rupture					

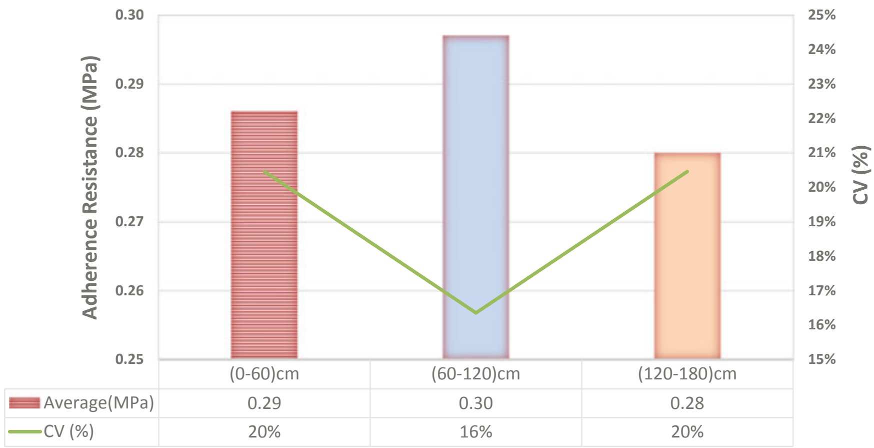

Fig. 19 Experimental results obtained at different heights

4.3 *Influence of the Application Height*

Figure 19 shows the values observed in the tested samples, separated according to the application time of the plaster paste.

In general, it was observed that there were no significant differences between the samples tested in the lower, central and upper planes with the plaster paste, regardless of the base to which it was applied. This fact stems from the technique of applying this coating, which is not made in a cast, as with the cement mortars (Scartezini 2002), which forces the applicator to push the mass against the wall and, thus, reduces the dispersions and the influence of ergonomics.

4.4 *Analyse of the Factors that Influencing the Bond Strength*

Although quite high, the variation coefficients of adhesion resistance obtained can be considered, for the most part, acceptable. This property measures the interaction between the mortar and the substrate and, therefore, depends on the characteristics associated with these two materials (Scartezini 2002).

In addition to the materials, it is essential to point out that other factors contribute to this high variation, such as the mortar application method, the craftsperson, and the intrinsic characteristics of the test method itself.

The obtained results lend themselves to the development of graphs that make more visible the interference of these variables: base type, cut type, and tested height, in relation to the tensile strength. The base type utilized had a significant influence on the values of bond strength of the coating, as seen in figures above. Regarding the cut type, a small decrease was noted in the results in all blocks where the cut was performed superficially. Regarding heights, all bases in the heights between 0.6 and 1.2 m presented the best results, followed by heights between 1.2 and 1.8 m, and finally the heights between 0 and 0.6 m gave the worst results.

In general, lower values of adhesion were observed in ceramic blocks as compared to concrete blocks. Probably the more porous and rougher surfaces of the concrete blocks allowed for a more substantial amount of plaster paste pore penetration, contributing to the adhesion.

5 Conclusions

The bond strength test was found to have high variability due to the characteristics of the system and application themselves. The same is true with a large number of specimens tested (480 in the four bases) where the average coefficient of variation obtained was 41%.

Although some bond strength results stand out more than others, it can be observed that, compared to the requirements for cement mortar coatings, the plaster paste met the minimum required values.

The first point to note is the issue of the dispersion of the results. As expected, the application of plaster in concrete blocks presented a smaller dispersion than in the ceramic blocks; that is, it shows a greater homogeneity of the utility rendered.

For the ceramic block bases, the ruptures occur predominantly in the plaster layer, very close to the interface region, and therefore are characterized as a rupture due to cohesion failure.

For concrete block bases, ruptures almost invariably occur within the substrate due to the failure of block cohesion. This fact was denoted as a limiting factor in the bond strength value for this type of substrate.

The substrate type is mainly responsible for the variation in bond strength and is hugely significant. Concrete blocks provide bond strength much higher than the values produced by ceramic blocks.

The so-called “outer layer”, which would be the first layer of the plaster coating, produced acceptable results in relation to the tests. An excellent professional together with superior materials and tools are vital aspects of perfect performance.

After testing and analysis of basic statistics, it was observed that the results in the concrete bases were more satisfactory, both in the surface cuts as well as in the cuts through to the base. This result is due to the higher porosity factor in the concrete bases than in the ceramic bases. However, all the tested specimens had positive results, demonstrating good adherence.

Adhesion is the property that the coating has to resist the tensions acting at the interface with the substrate, depending on the interaction between the layers that constitute the system for which the evaluation is intended (base, base preparation, and coating).

Several factors may influence the adhesion of the plaster coating, such as the dosage of the paste, the exposure conditions, the avidity for water, and the roughness of the base. These are issues that have spawned several studies by different authors for a better understanding of the subject. Among these, one factor is of particular importance, which is the ergonomics of the operator during the application of the mortar to the wall, the height of which extends from the floor to the ceiling, as well as the application energy to the base, which varies according to its manual casting.

There was no marked variation regarding the height of the application of the plaster. The results in the extremities were inferior in all bases, albeit satisfactory.

In the centre of the panels, there was a tendency towards a more significant variation compared to the extremities, which indicates an excellent utility performance, since the median height enables more significant proximity of the craftsperson's arms to the work area, requiring less application effort, providing more homogeneity.

In the three casting conditions, the results showed that the height of the area to which the material is being applied influences significantly the craftsperson's ability in the performance of coating application, which could be verified by the higher resistance levels and the smaller dispersion values in the tested samples.

Ergonomics influenced the results obtained in the adhesion tests, the best results being observed in the samples tested in the centre areas (between 0.6 and 1.2 m) of the wall.

The experiments presented in this study, part of the author's master's dissertation, and highlight the influence of the base type (ceramic and concrete blocks, structural and non-structural) and the depth of the cut (deep or superficial) in the mechanical adhesion behaviour of the gypsum pastes used as a vertical internal coating.

It is noteworthy that, as already observed in other studies, the ergonomics of the craftsperson, evaluated in separate tests at different heights, was not relevant in the data studied. This element should come from an application technique using continuous pressure of the paste on the wall, as opposed to the energetic roughcasting commonly employed in mixed cement mortars.

In all cases, bond strength values higher than 0.20 MPa were found, which meet the requirements presented by NBR13281 (2005) for indoor use, the very situation in which plaster paste coatings were studied in this research.

It is important to note that the results presented should be restricted to the materials used in this research, and cannot be generalized in regard to all types of blocks and plaster used in construction work. Never-the-less, the significant amount of samples used (480 in total) represents a significant behaviour trend regarding this type of coating solution employed in interior building environments.

References

Baltar CAM, Bastos FF, Luz A (2005) Benvindo. Gipsita. Rio de Janeiro, Cetem

Barbosa AA, Ferraz AV, Santos GA (2014) Caracterização química, mecânica e morfológica do gesso β obtido do polo do Araripe. UNIVASF, Petrolina

Carasek H (2007) Materiais de Construção Civil e Princípios de Ciência e Engenharia de Materiais. São Paulo, IBRACON

Carasek H (2010) Argamassas. In Isaia GC (ed) Materiais de Construção Civil e Princípios de Ciência e Engenharia de Materiais. São Paulo: IBRACON, vol 2, Cap. 28, pp 893–944
Carasek H, Cascuco O, Scartezini LM (2001) Importância dos materiais de aderência dos revestimentos de argamasse. IV Simpósio Brasileiro de Tecnologias das Argamassas. Brasília, Beazil
Carasek H, Cascuco O, Santos MSJ, Lemos N (2011) Avaliação em obra da resistência superficial de revestimentos de argamassa. Rev ALCONPAT 1(2):118–140
Costa e Silva AJ, Cabral FMS, Neves TH, Lima BCSB (2017) Estudo comparativo da aderência de revestimentos de gesso aplicados por projeção mecânica e manual. XII Simpósio Brasileiro de Tecnologia das Argamassas, São Paulo
Flores-Colen I, Brito J, Branco F (2009) In situ adherence evaluation of coating materials. Exp Tech 33(3):51–60
Freitas VP, Corvacho H, Quintela M, Delgado JMPQ (2014) Assessing the durability of mortar tiles—A contribution for a prediction model. Eng Fail Anal 44:36–45
Ioppi PR (1995) Estudo da aderência das argamassas de revestimento em substratos de concreto. Florianópolis. MSc Thesis, Universidade Federal de Santa Catarina
Luz AB, Baltar CAM, Freitas EJG, Silva AP (2001) Mineração São Jorge. In: Sampaio JA, Luz AB, Lins FAF (eds) Usinas de Beneficiamento de Minérios do Brasil, pp 241–249
Lyra AC (1986) O mercado de gipsita e gesso no Brasil. Vortal Cadeia Produtiva do Gesso, 2002. http://www5.prossiga.br/gesso/index.html NOLHIER M. Construire en plâtre. França, L'Harmattan, 1986
Maciel LL, Barros MMS, Sabbatini FH (1998) Recomendação para Execução de Revestimentos de Argamassa para paredes de vedação internas e externa e tetos. São Paulo, Brazil
Melo A, Costa e Silva AJ, Torres SM, Delgado JMPQ, Azevedo A (2019) Influence of the contact area in the Adherence of Mortar—Ceramic tiles interface. Constr Build Mater (Accept)
Naderi M (2005) Friction-transfer test for the assessment of in situ strength and adhesion of cementitious materials. Constr Build Mater 19:454–459
NBR13281 (2005) Argamassa Para Assentamento e Revestimento de Paredes e Tetos. Rio de Janeiro, ABNT
NBR 13528 (2010) Revestimentos de paredes e tetos de argamassa inorgânicas—Determinação de resistência de aderência à tração. Rio de Janeiro, ABNT
NBR 13749 (2013) Render made of inorganic mortar walls and ceillings applications—Specification. Rio de Janeiro, ABNT
NBR 13755 (2017) Revestimentos cerâmicos de fachadas e paredes externas com utilização de argamassa colante — Projeto, execução, inspeção e aceitação — Procedimento. Rio de Janeiro, ABNT
NBR 7184 (1992) Hollow concrete masonry blocks—Compressive strenght testing. Rio de Janeiro, ABNT
NBR 7200 (1998) Render made of inorganic mortars applied on walls and ceilings—Procedure for application. Rio de Janeiro, ABNT
NBR 6461 (2005) Bloco cerâmico para alvenaria - Verificação da resistência à compressão. Rio de Janeiro, ABNT
Nita C, Pileggi RG, Cincotto MA, John WM (2004) Estudo da reciclagem do gesso de construção. I Conferência latino-americana de construção civil sustentável X encontro nacional de tecnologia do ambiente construído. São Paulo, Brazil
Paula P, Delgado JMPQ (2017) Hygrothermal performance of gypsum plaster houses. Diffus Found 14:128–157
Paula P, Vázquez da Silva M, Delgado JMPQ (2017) Numerical analysis of hygrothermal building performance of gypsum houses in different Brazilian climates. Diffus Found 10:132–148
Peres L, Benachour M, Santos VA (2008) Gesso produção e utilização na construção civil. Recife, SEBRAE

Santos HB (2008) Ensaio de aderência das argamassas de revestimento. MSc thesis in Civil Engineering of Escola de Engenharia da UFMG, Belo Horizonte

Scartezini LM (2002) Influência do tipo e preparo do substrato na aderência dos revestimentos de argamassa: Estudo da evolução ao longo do tempo influência da cura e avaliação da perda de água da argamassa fresca. Goiânia