Statistical analysis of test methods to evaluate rendering surface properties

Análises estatísticas de resultados de ensaio de avaliação da resistência superficial de revestimentos de argamassa

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Abstract

The objective of this study is to discuss the results of two test methods used to evaluate rendering surface properties: the superficial tensile strength (STS) and the pendulum rebound hammer (which provides the rebound index – RI), besides evaluating, additionally, the tensile bond strength (BS). The studied variables were the type of mortar (job-site mortar and dry-mix mortar) and the render moisture at the time of testing (in four contents). For each test, a minimum of 45 determinations was planned per analyzed situation, totaling 1411 valid results, which allowed a consistent statistical analysis and an in-depth discussion of the methods. The STS and RI tests were sensitive at a 95% confidence level to differentiate mortars from different strengths and were therefore approved for this evaluation. The most significant effect in all statistical models tested was the type of mortar. The variable moisture condition of the render was significant only for the results of STS and BS. In such cases, tests performed with wet or saturated renders presented much lower strength results compared to those carried out with air- dried renders. It was possible to obtain a significant correlation between STS and BS, with a high coefficient of determination.

Keywords: Rendering. Mortar. Superficial tensile strength. Pendulum rebound hammer. Statistical analysis.

Resumo

O presente trabalho visa discutir resultados de dois métodos de ensaio que avaliam propriedades da superfície de revestimentos de argamassa: resistência superficial à tração (RST) e esclerometria de pêndulo (que fornece o índice esclerométrico - IE), além de avaliar, complementarmente, a resistência de aderência à tração (RA). As variáveis estudadas foram: tipo de argamassa (preparada em obra e industrializada) e umidade do revestimento no instante do ensaio (4 teores). Para cada ensaio foram planejados no mínimo 45 determinações por situação analisada, totalizando 1411 resultados válidos, o que permitiu uma análise estatística consistente e uma discussão aprofundada dos métodos. Os ensaios RST e IE foram sensíveis, a um nível de confiança de 95%, para diferenciar argamassas de resistências distintas, ficando, portanto, credenciados para tal avaliação. O efeito mais significativo em todos os modelos estatísticos testados foi o tipo de argamassa. A variável condição de umidade do revestimento foi significativa somente para os resultados de RST e RA. Nesses casos, ensaios realizados com os revestimentos molhados ou saturados tendem a apresentar resultados de resistência muito mais baixos do que quando eles estão secos ao ar. Foi possível obter uma correlação significativa entre RST e RA, com um alto coeficiente de determinação.

Palavras-chaves: Revestimento. Argamassa. Resistência superficial à tração. Esclerômetro de pêndulo. Análises estatísticas

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Introduction

Wall rendering mortars must fulfill determined functions in order to permit a satisfactory performance for buildings during their service life. Regarding facade renders, their main functions are:

(a) to protect masonry and structure against weathering action;

(b) to integrate the building envelope system, contributing to thermal and acoustic insulations, watertightness, fire safety, wear and superficial impact strengths; and

(c) to regularize the surface of building vertical envelope elements, working as a base for decorative finishing and assisting in the building appearance.

In order to properly comply with these functions, renders must have characteristics and properties compatible with the conditions they will be exposed to, with the conditions of execution and the nature of the substrate, with the performance specifications and the finishing layer designed. Among the main properties of renders are the bond capability to the substrate, the mechanical strength (mainly superficial), capability to absorb strains, the water and vapor permeability.

The superficial strength is an important requirement for not only the renderings that will be finished with paint, but above all, for the mortar-bed that constitutes a tile coating system, since there are high tensions on this layer surface because of the tiles' weight. Another situation where the superficial strength becomes very important is regarding one-coat decorative renders; once they are constituted by their own decorative layer, and any damage caused on their surface will create the necessity to remove and fix the render of a larger region than the damaged one, considering the difficulty to make corrections without color variation (CRESCÊNCIO; BARROS, 2015).

Despite the importance of this property, there is still a lack of studies regarding superficial strength and there are not many test methods available for its evaluation. Therefore, the present paper aims at the discussion of results from two test methods that evaluate rendering surface properties through a laboratory experimental research, besides the search for correlations between these two tests results and the results from the bond strength test (the only method specific for the evaluation of renders performance standardized at the present moment in Brazil). In this research a great number of repetitions was conducted in each test, which permitted a consistent statistical analysis and a deep discussion of the methods. Additionally, the paper aims at the discussion of the influence of rendering mortar moisture when the tests were carried out.

Literature review regarding test methods to evaluate superficial strength

The superficial strength of wall rendering mortars has been evaluated with the use of tests that measure different parameters, such as abrasion resistance, impact resistance, surface hardness, scratch resistance and superficial tensile strength. Hereafter, a brief review regarding some test methods used to determine these parameters is presented. For this, many methods are mentioned, and the ones adopted in this experimental research are discussed with more details.

Abrasion resistance

Two methods may be mentioned for the evaluation of the surface wear resistance by abrasion of renders. The first one is the method prescribed by the Portuguese National Laboratory of Civil Engineering - LNEC - FE-Pa 28, cited by Cincotto, Silva and Carasek (1995). This method uses an equipment named Martinet Baronnie and the abrasion resistance is obtained through the observation of the surface state submitted to friction with a sandpaper that is compressed on the render with increasing masses.

The second method is prescribed by the MR-9 document from RILEM (1982), which measures the abrasion resistance through the quantification of the render mass collected after the superficial wear is produced by a circular brush with plastic bristles, coupled to an electric motor that rotates at a standard speed during 90 seconds.

Impact resistance

The same Martinet Baronnie equipment used to evaluate the abrasion resistance may also be used to evaluate renders in terms of impact resistance to hard bodies by means of two methods: LNEC FE-Pa 25 – Sphere impact test and FE-Pa 26 – cut-off impact test. The sphere impact test provides data on the deformability of the render and measures the mass diameter produced by the impact of a steel sphere of 50 mm diameter. The cut-off impact test aims at the evaluation of the render strength against the impact of hard cutting bodies through the impact of a metallic dented block, providing information related to render cohesion. The studies of Veiga and Carvalho (2000) and Flores-Colen, Brito and

Freitas (2009) present details of the methodology and a broad discussion of the test results.

The method used to verify the impact resistance of External and Internal Vertical Envelope Systems for hard bodies was recently standardized in Brazil as an appendix in NBR 15575-4 (ABNT, 2013). Although this test method performs a wider evaluation, namely, a system evaluation, and not specifically a mortar render evaluation, it may be considered within this context.

Surface hardness

The TC 127-MS D.7 is a method that has been used to determine the surface hardness of mortar renderings (RILEM, 1998), through the Rebound Index (RI) determination, using a Type PM pendulum hammer. The test consists in the production of an elastic reaction by the impulses of a known mass after colliding against the surface of the render. It is possible to measure the amount of energy recovered from the mass rebound, which permits the acquisition of the hardness index from the surface tested (rebound value). According to the procedure, 9 measurements uniformly divided over the area to be judged must be carried out, and the result, the rebound value, is represented by the median value. The softer the material, the greater the amount of energy absorbed, and smaller the rebound height (VEIGA; CARVALHO; AGUIAR, 2004). According to the authors, the use of this method implies in the validation and calibration studies for each rendering under evaluation. Table 1 presents the evaluation criteria for mortars.

Scratch resistance

The LNEC suggests a method to evaluate the scratch resistance of wall renderings. In this method, LNEC FE-Pa 27, the Martinet Baronnie equipment is also used. The process consists in verifying the incidence or the absence of degradation through scratch or pull-out, when the render is submitted to the action of a metallic disk edge in rectilinear movement and charged with increasing masses (CINCOTTO, SILVA, CARASEK, 1995).

Many other empirical tests are often used by the construction sector to evaluate on site the superficial strength of renderings by scratch. As an example, the qualitative methodology presented by Ceotto, Baduk and Nakakura (2005) may be cited, which proposes the evaluation of the surface of the mortar after scratching them with a cutting instrument: trowel or nail.

Superficial Tensile Strength - STS

This method is based on the tensile strength evaluation (pull-off resistance) of a superficial portion of the rendering mortar. For this, part of the test methodology prescribed by NBR 13528 (ABNT, 2010) to determine the tensile bond strength of rendering mortar is followed, eliminating, however, the stage of cutting the render layer until reach the substrate on the superficial resistance evaluation. Many researchers and professionals have been using this method for more than 25 years for floor screeds and renderings, despite the fact it is not standardized in Brazil. Among these researchers, the works of Barros and Sabbatini (1991), Pereira, Carasek and Francinete Junior (2005), Temoche-Esquivel *et al.* (2005) and Carasek *et al.* (2008, 2011) can be highlighted. These authors analyzed the influence of several factors (cure, age, surface finish) on the results of surface resistance and found that the test method, despite a relatively high variability (CV ~36%), has a great potential in terms of renders evaluation. They also obtained strong correlations between STS values and other tests (bond strength, surface hardness by pendulum hammer and water absorption by Karsten tube).

Currently, the review project of the NBR 13755 (ABNT, 2017) standard, related to the execution procedure of facade tile coating, defines this test method to determine superficial resistance in its Appendix B, in order to evaluate mortar-beds. This project also presents evaluation parameters (Table 2).

Table 1 **- Pointing hardness classification**

Class	Hardness (RI)	Indicated quality
0 (zero)	<15	Very soft
A	15-25	Soft
B	25-35	Moderate
C	35-45	Normal
D	45-55	Hard
E	>55	Very hard

Source: Rilem (1998).

Table 2 – **Acceptance requirements and criteria for tile coating system regarding the mortar-beds superficial tensile strength, from a total of 12 samples that composes the sampling, according to the review project from NBR 13755 (ABNT, 2017)**

Test results	Acceptance criteria
At least 8 smples ≥ 0.5 MPa	Approved
0.3 MPa ≤ samples < 0.5 MPa	Refer to the project
Less than 8 samples ≥ 0.3 MPa	Failed

Another test method to evaluate the pull-off resistance is the peeling test, also known as *Scotch tape test*. The RILEM, in the MR 18 (RILEM, 1982) method, proposes a simple methodology to evaluate the render's surface resistance, through the mass determination of the material removed from the surface, using a standardized piece of adhesive tape. Drdácký *et al.* (2015) in recent study established limits for the application, reliable procedures and a standard protocol for testing the cohesion characteristics of brittle and quasi-brittle materials, mainly mortars and stones, by *Scotch tape test*.

Materials and methods

In order to analyze different methods for the evaluation of the superficial strength of rendering mortars, an experimental program was delineated, according to the description below.

The variables adopted for this research were:

(a) independent variables:

- the type of mortar: two variation levels: a job-site mortar and a dry-mix mortar; and

- the water content of the renders when tests were conducted: four levels of variation: from dry to saturated (M1, M2, M3 and M4).

(b) dependent variables:

- the superficial tensile strength;

-the impact strength using a pendulum rebound hammer; and

- the tensile bond strength.

Materials

Concrete standard substrate was used as background for the rendering mortars, with dimensions of 25 cm x 50 cm and thickness of 20 mm. Substrates were manufactured and tested according to NBR 14081-2 (ABNT, 2015).

Two distinct types of mortar were used in this research: a multi-functional dry-mix mortar and a job-site mortar (conventionally prepared on site in Brazil).

The dry-mix mortar, constituted by Portland cement, mineral aggregates and chemical additives, was prepared with water/dry materials ratio of 0.15.

A proportion 1:2:9 (cement:lime:sand, by volume) was adopted for the job-site mortar. CP II E-32 Portland cement, CH-III hydrated lime and natural quartz sand of fine grade were used in the mortar preparation. The water/dry materials and water/cement ratios adopted were 0.23 and 2.44, respectively.

The characterization of the materials used in the job-site mortar is shown in Tables 3 to 5 and they comply with the Brazilian standards.

The average result obtained from mortar characterization tests on fresh and hardened states is summarized in Table 6.

Preparation and application of rendering mortar

Mortars were mixed in a concrete mixer of 400 liters capacity, in a laboratory environment. The dry-mix mortar was placed as received in the mixer and, after 50% of water added, it was mixed for 2 minutes. After a slaking stage during 1 minute, the remaining water was added and mixed for 2 minutes again. For the job-site mortar, after an initial homogenization of the dry materials (cement, lime and sand), 50% of the water was added and mixed for 5 minutes. After a slaking stage during 2 minutes, the remaining water was added and mixed for 5 minutes again.

Before mortar application, the concrete substrate face to be coated was brushed to remove dust and other materials that could inhibit mortar/background bond.

Aiming at the standardization of the application process and, therefore, trying to guarantee the lowest variability of results as possible, which is imposed by the rendering execution, the mortars were applied using a compressed air mechanical system (pressure of 100 psi, 0.70 MPa), maintaining a distance of approximately 30 cm from the panels to be coated. The renders' thickness was fixed in 25 mm ± 2 mm, guaranteed by metal guides. They were straightened with a wood trowel and received superficial finish with a wet sponge, simulating job-site actual conditions (Figure 1).

All renders were cured for a period of 6 months ± 15 days, in order to obtain satisfactorily consolidated mortars; after this period, the renders were tested. In this period, the laboratory environment was: temperature 20 to 32 ºC and relative humidity 55 to 80%.

Conduction of the tests

Aiming at the definition of the render places to be "reserved" for each test, per panel, without local superposition, a template with 32 squares of approximately 50 mm side was produced, maintaining a minimum separation of 10 mm from the borders. An example of these maps with the points to be tested is illustrated in Figure 2. It is emphasized that the position reserved for each test in the multiple templates was totally randomized.

Table 3 - **Cement Characterization**

Test method	Characteristic/Property		Results
NBR 16372 (ABNT, 2015)	Blaine fineness (cm²/g)		4032
NBR 11579 (ABNT, 2012)	0.075 mm sieve residue (%)		1.38
NBR 12826 (ABNT, 2014)	0.045 mm sieve residue (%)		7.84
NBR NM 65 (ABNT, 2003)	Initial setting time (h, min)		3 h, 5 min
	Final setting time (h, min)		4 h, 30 min
NBR 7215 (ABNT, 1996)	Compressive Strength (MPa)	3 days	21.8
		7 days	29.6
		28 days	39.3
NBR NM 14 (ABNT, 2012)	MgO content (%)		2.37
	SO_3 content (%)		2.22

Table 4 - **Hydrated Lime Characterization**

Test method	Characteristic	Results
NBR 6473 (ABNT, 2003)	Carbonic anhydride – CO_2 (%)	12.36
	Ca and Mg unhydrated oxides (%)	14.02
	CaO + MgO (%)	97.14
NBR 9289 (ABNT, 2000)	0.6 mm sieve residue (%)	0.02
	0.075 mm sieve residue (%)	12.11

Table 5 – **Sand Characterization**

Test method	Physical characteristic	Results
NBR NM 45 (ABNT, 2006)	Unit weight (kg/dm^3)	1.43
NBR NM 52 (ABNT, 2009)	Specific gravity (kg/dm^3)	2.64
NBR NM 248 (ABNT, 2003)	Fineness modulus	1.85
NBR NM 248 (ABNT, 2003)	Nominal maximum aggregate size (mm)	2.4
NBR NM 46 (ABNT, 2003)	Fine content (%)	0.5

Table 6 - **Mortar characterization tests on fresh and hardened (28 days) states**

Determination	Test method	Mortar	
		Dry-mix	Job-site
Consistency (mm)	C780 (AMERICAN..., 2017)	40	45
Bulk density (g/cm^3)	NBR 13278 (ABNT, 2005)	1.70	1.88
Air content (%)	NBR 13278 (ABNT, 2005)	22	10
Compressive strength (MPa)	NBR 13279 (ABNT, 2005)	8.40	4.17
Flexural tensile strength (MPa)	NBR 7222 (ABNT, 2011)	3.11	1.38
Dynamic Young's modulus (MPa)	NBR 15630 (ABNT, 2008)	8.30	---

Figure 1 - **Rendering execution: (a) application of mortar using spray machine: hopper spray gun type; (b) render straightening; and (c) surface finishing with sponge**

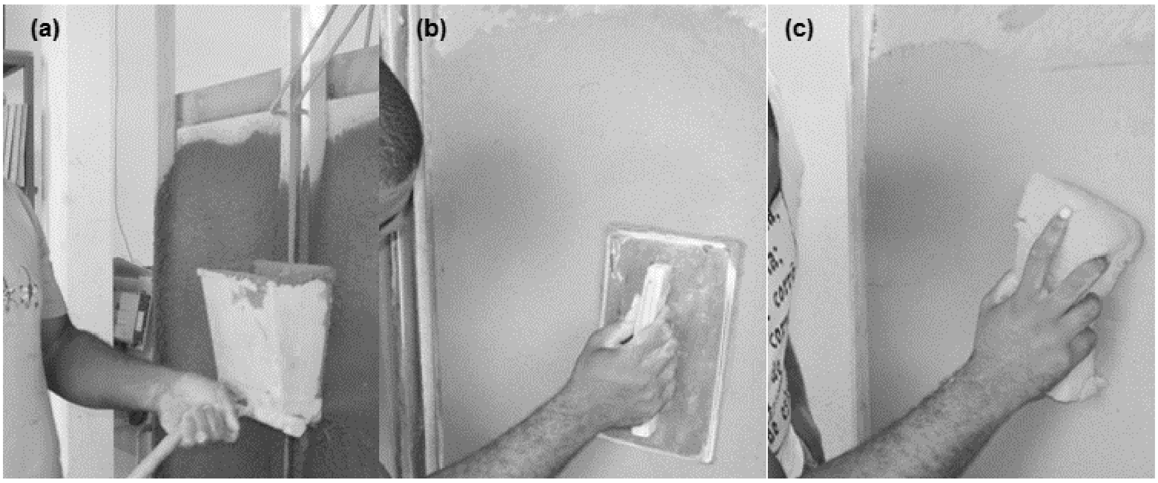


Figure 2 - **Example of map with the location of the points to be tested on the renders**

Before the conduction of the tests, renders were prepared in order to fit the pre-defined conditions, such as fixed variables of the research, according to the following aspects:

(a) the oven-dry condition (M1) – the rendering panels were maintained in a laboratory environment; 24 hours before the conduction of the tests, these panels were put inside an oven at (105 ± 5) °C temperature. From the oven, the panels were conducted to a desiccator to cool until the test;

(b) the environment moisture condition (M2) – the rendering panels were maintained in a laboratory environment (natural condition) until the moment of the test;

(c) the humid condition (M3) – the panels were maintained in laboratory environment; straight before the moment of the test, their rendering faces were partially immersed in 30 mm of water, for a 10-minute-period; and

(d) the saturated condition (M4) – the rendering panels were fully immersed in a water tank during 48 hours before testing, taken out only at the moment of the test.

Right before the conduction of the render tests (superficial strength and bond strength), the superficial moisture of each panel was determined, through the Moisture Meter James Instruments Inc. AQUAMETER™. The average results obtained from all rendering panels used on this research are shown in Table 7.

The methods of the tests conducted on the renders are hereafter explained.

Test with dynamometer: determination of the superficial tensile strength

This method was based on the tensile strength evaluation of the render superficial portion, through an adaptation of the methodology used to determine the tensile bond strength, prescribed by NBR 13528 (ABNT, 2010).

To do so, there was no cutting the mortar layer for the specimens' delimitation, the metallic pull-head plate (5 cm diameter) was directly glued on the render, using a polyester adhesive. A tensile dynamometer was used for the pull-off test, with a load capacity of 1kN and resolution of 0.5 N, from Consultare/Alfa Instruments (Figure 3). The initial sample size was 45 specimens for each situation studied, reaching the total planned of 360 pull-off tests.

Pendulum Rebound Hammer Test: determination of the Rebound Index (RI)

The methodology adopted to determine the superficial hardness through the RI followed the TC 127 – MS D.7 document (INTERNATIONAL…, 1998). Initially, the rendering panel was set on a metal base fixed on the wall, in order to test the vertical render; therefore, the equipment was properly positioned on points previously defined for this test. A Pendulum Rebound Hammer Seidner PT type was used.

The test procedure, illustrated in Figure 4, was carried out once in each place determined for the conduction of the test, eliminating consecutive impacts on the same place. For each situation investigated, 100 readings of RI were performed, reaching a total of 800 readings on this research.

Determination of the tensile bond strength

The determination of the tensile bond strength followed the methodology prescribed by NBR 13528 (ABNT, 2010). After cutting the mortar layer using a core drilling machine, the metallic pull-head plate (5 cm diameter) was glued on the render with a polyester adhesive. A dynamometer was used to the pull-off test, with a capacity of 1 kN and resolution of 0.5 N from Consultare/Alfa Instruments. The initial sample size was 45 specimens for each situation studied, reaching the total planned of 360 bond tests.

Statistical evaluations of the results

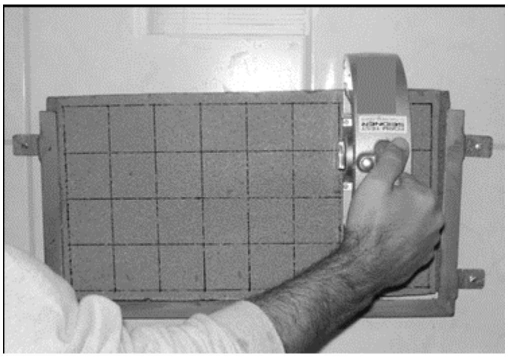
As means to reach a better discussion and interpretation, the results obtained from the tests were submitted to a series of statistical analysis, all of them considering a level of significance of 5%.

Table 7 – **Mean moisture determined**

Code	Condition	Mean superficial moisture
M1	Oven drying	5%
M2	Environment	13%
M3	Humid	35%
M4	Saturated	86%

Figure 3 – **Conduction of the superficial tensile strength test**

Figure 4 – **Conduction of the Pendulum Rebound Hammer test**



Initially, each group of individual results was subjected to a descriptive analysis, which extracted the following answers: the assessment of normality using Kolmogorov-Smirnov (K-S) test, mean and coefficient of variation (CV). Besides the fact of the K-S test being a procedure with more than 99.9% accuracy for normal distributions (TORMAN; COSTER; RIBOLDI, 2012), the visual analysis of frequency histograms were additionally carried out, in order to investigate specially the normality in conditions where the p-value from K-S test was closed for the value of 0.05 (significance limit). After the verification of the distributions' normality and preliminary analysis of the mean and CV, the analysis of variance (ANOVA) was conducted.

The ANOVA was carried out by means of a Two-way Project, from two manageable factors for various fixed levels. The generic statistical model, which expresses this analysis, is presented in Equation 1, according to Ribeiro and Caten (2011):

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \qquad \text{Eq. 1}$$

Where:

μ is the general mean;

α_i is the effect of i-nth level of A (water content on this case);

β_j is the effect of j-nth level of B (mortar type on this case);

$(\alpha\beta)_{ij}$ is the AB interaction effect; and

ε_{ijk} is the random error measurement.

In order to verify the significance of these factorial projects, in each one of the situations studied, a result from ANOVA with the addition of results from the model correlation and determination coefficients were synthesized. The *Fisher* parameter (Fcal) values were compared with the fixed values (Ftab). The Ftab value corresponds to $F\alpha = 0.05$ (ν1, ν2), where ν1 and ν2 are the freedom level of the evaluated effect and residue, respectively.

After ANOVA, a multiple comparison of the mean using the *Duncan* test was performed, with the intention of grouping the means that significantly differ from each other. On the chart representation, the group separation under statistical point of view was indicated by dashed vertical lines.

Additionally, there was a perception for the need in correlating the tests results by using mathematical models (linear regression and correlation). The *Pearson* scale was used for the correlation analysis, which indicates the correlative tendency between two variables, including the tendency to directly correlate (positive indices) or to contrarily correlate (negatives), according to the classification in Table 8.

The computational software used were RStudio© 0.99 and Statistica12.

Results

The individual results for each one of the tests were submitted to a series of statistical analysis, according to what is described in section 3.4. The individual values obtained from the tests, which represent a total of 1411 valid results, may be checked in the study of Alves (2009). The results of the descriptive analysis conducted with the tests data are summarized in Table 9.

Hereafter the results are initially evaluated for each type of test carried out, and at the end, some correlations among the tests are made, and a discussion about the moisture effect is conducted.

Superficial Tensile Strength - STS

The results from the K-S normality test show a normal distribution for all the data groups evaluated. A visual analysis was also conducted for all the moisture variation levels to both mortars, proving the tendency for the normal distribution of the STS results. Figure 5 displays the two histograms developed, as an example for the M2 moisture group with the dry-mix and job-site mortar coatings, showing the normal tendency of the frequencies. For this case, slight asymmetries were observed (negative to the right on the dry-mix mortar and positive to the left on the job-site mortar), and both distributions were classified as leptokurtic.

The frequencies of the results normally distributed allow the use of classic statistical methods, as well as the use of the mean as a characteristic value. In this sense, quite distinct means were observed for the groups, varying between 0.04 and 0.56 MPa, with the greater value equivalent to 14 times the lowest mean value obtained, which denotes the influence of the variables studied (mortar and moisture) on the STS results, i.e. the test method exhibits sensibility to distinguish renders produced with different mortars and water contents.

Table 8 – **Parameters for the interpretation of the coefficient of correlation – R**

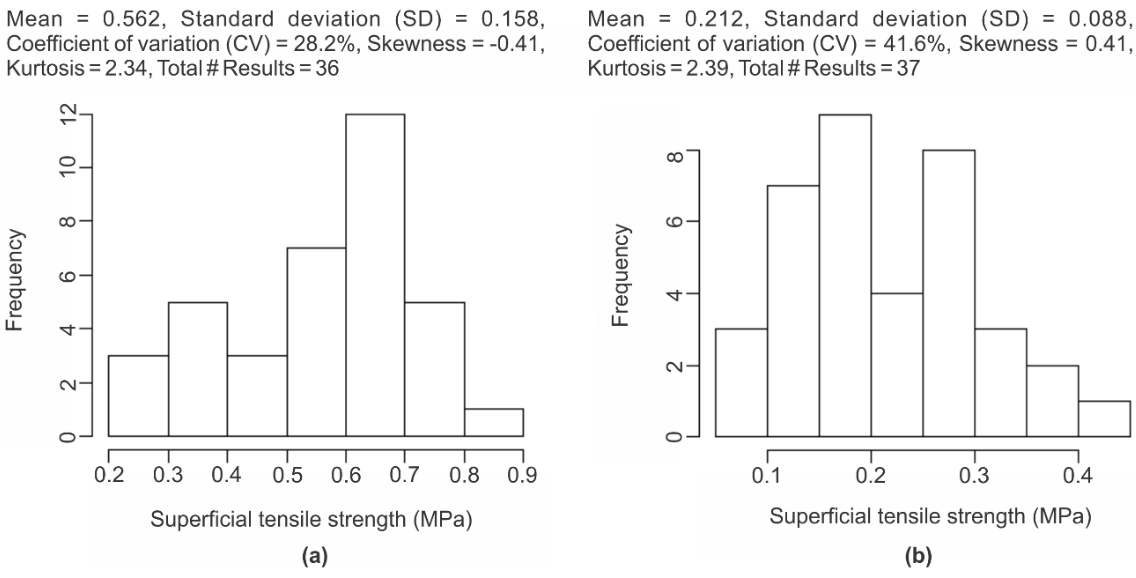
Correlation (positives or negatives)	Interpretation
0.90-1.00	Very strong correlation
0.70-0.90	Strong correlation
0.50-0.70	Moderate correlation
0.30-0.50	Weak correlation
0.00-0.30	Insignificant correlation

Source: Mukaka (2012).

Table 9 – **Descriptive analysis**

Mortar	Moisture condition	Superficial Tensile Test Total = 315 tests				Rebound Hammer Test Total = 800 tests				Bond Strength Test Total = 296 tests			
		n	K-S p-value	Mean (MPa)	CV (%)	n	K-S p-value	Mean (RI)	CV (%)	n	K-S p-value	Mean (MPa)	CV (%)
Dry-mix	M1	40	0.836	0.518	32.4	100	0.070	71	9.0	35	0.677	0.290	59.9
	M2	36	0.262	0.562	28.2	100	0.377	71	11.4	35	0.958	0.434	38.6
	M3	39	0.640	0.267	24.7	100	0.050	71	8.4	38	0.988	0.216	34.9
	M4	41	0.190	0.087	67.5	100	0.040	71	8.4	42	0.345	0.108	58.1
Job-site	M1	45	0.550	0.189	43.8	100	0.550	55	8.8	34	0.276	0.111	64.2
	M2	37	0.934	0.212	41.6	100	0.354	55	8.4	42	0.116	0.151	39.1
	M3	38	0.774	0.135	33.0	100	0.184	54	9.1	33	0.396	0.077	344
	M4	39	0.450	0.042	57.1	100	0.056	55	10.5	37	0.916	0.043	48.3
				Mean	41.0		Mean		9.2			Mean	47.2

Figure 5 – **Examples of histograms of superficial tensile strength frequencies developed for the M2 group: (a) dry-mix mortar; and (b) job-site mortar**



It is also observed the results from each group have a fairly high variability, high CVs, with the overall mean value of 41% and the highest value around 68%. This high variability of the results could be configured as a disadvantage for the test method. Nevertheless, it is worth mentioning that the high CVs are also obtained from the test to determine the tensile bond strength of the renders (test that originates the STS), reaching the same order of magnitude. The explanation for the high CVs is the high variability imposed by the materials (mortar and substrate), besides the process of render application. Henceforth, it is important to mention the nature of the materials involved: from the science of materials' point of view, the mortar coatings are fragile ceramic materials, which are characterized by the presentation of high dispersion in the results of rupture. In these cases, the fracture strength is extremely dependent on the probability of the existence of a deficiency which is capable of starting a crack.

However, after a more detailed observation of the CVs (Figure 6), two distinct zones of the coefficients of variation are noticed, a lower zone related to the moistures M1 and M3 (with a mean CV of 34%) and an upper zone (62% mean) when the render is saturated (M4). Therefore, based on the results of this research, it is possible to infer that the conduction of this test is not appropriate for saturated renders, what implies in a high variability of the results. This outcome must be confirmed with new studies in order to allow the generalization, although it is important to take into account that a previous research conducted on site (CARASEK *et al.*, 2008) reached a result with the same tendency, i.e. the lower CV was obtained to the dry render (natural moisture), in comparison with the results of the renders in humid and saturated condition.

The summary of the variance analysis carried out is presented in Table 10, in order to verify the effects of moisture and type of mortar on the STS results.

The ANOVA results show the factorial model adopted is significant when the calculated and tabulated Fisher parameters are compared. It also indicated that 77% of data variation is explained by the model. The main effects, moisture and type of mortar, exert influence on superficial strength. The interaction between these effects also showed to be significant, demonstrating that the type of mortar is not independent, i.e. the STS result to a given mortar depends on its moisture at the moment of the test. Another fact verified is that the type of mortar exerts a greater influence on the property studied than the render moisture condition. Figure 7 illustrates the estimation of the overall mean of the STS results for the moisture levels, indicating the groups significantly different from each other, defined by the Duncan test.

Figure 6 - **Coefficients of variation of the STS test in function of the render moisture**

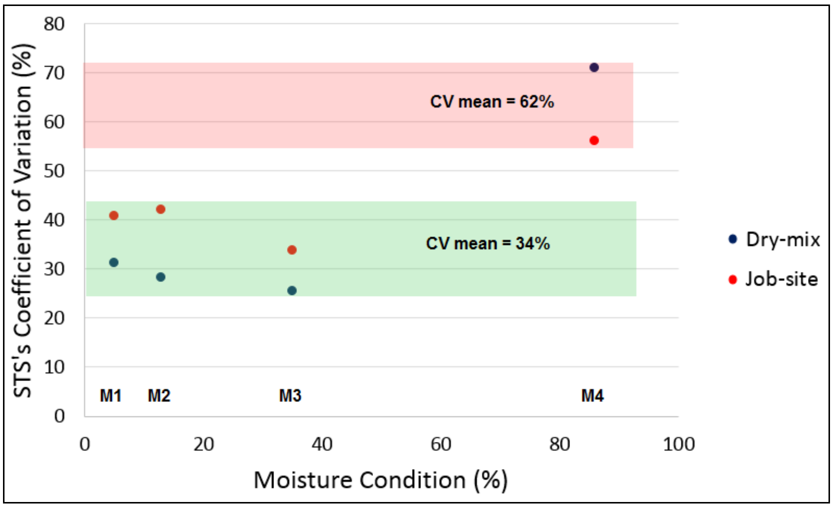
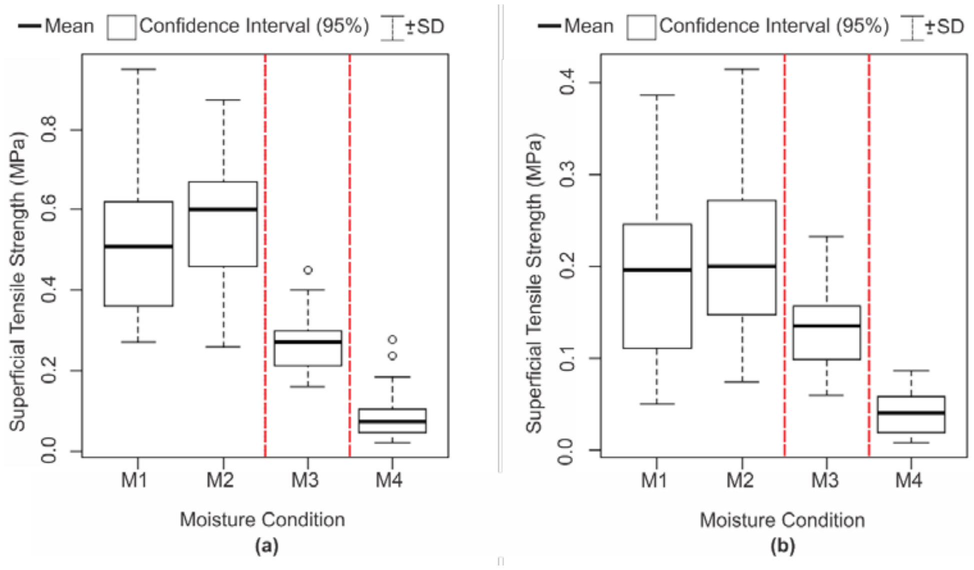


Table 10 - **ANOVA for the results of superficial tensile strength**

Effect	Sun of squares	df	Mean square	Fcal	Ftab (F_{α} = 0.05)
Model	9.895	7	1.414	146.83	2.04
Moisture	5.211	3	1.737	180.4	2.64
Mortar	3.598	1	3.598	373.7	3.88
Moisture x Mortar	1.321	3	0.440	45.7	2.64
Error (Residuals)	2.956	307	0.010	-	-

Note: Coefficient of determination (R^2) = 0.77;
Correlation coefficient (R) = 0.88.

Figure 7 - **Estimation of overall mean of the STS values**



The test of mean multiple comparison showed equality to the test results at M1 and M2 moistures from the statistical point of view, while the other moistures formed distinct groups. It is also observed as the render moisture increases, the superficial strength values abruptly decrease. Comparing the STS mean values obtained for the condition of air-dry moisture (0.56 and 0.20 MPa to dry-mix and job-site mortars, respectively) with the acceptance criteria proposed in Table 2, it is verified that only the render produced with dry-mix mortar would be possibly accepted.

Another interesting point of view is the estimation of the results' overall mean according to the type of mortar (Figure 8).

It is possible to observe that the results of renders produced with dry-mix mortar are approximately twice higher when related to those produced with job-site mortars, regardless of the moisture condition. This is expected since the dry-mix mortar mechanical strengths (Table 6) are much superior to the ones obtained from the job-site mortar.

Rebound Index - RI

In Table 9, where the descriptive analysis is presented, it is possible to observe the mean results of the Rebound Index were practically equal in the same type of mortar, despite the moisture variations. The low CVs values are also observed, inferior to 12% to all the set of results. This high homogeneity of the set of data may be a positive aspect of the test because it denotes a better precision of the measures obtained.

Regarding normality, only the dry-mix mortar set of results with the saturated renders (M4) did not present normal distribution, with p-value=0.04. The histogram of this set of values is shown in Figure 9. As the sets of data are quite homogeneous, the mean is maintained as an adequate parameter to represent the samples. Also, this set of values presents normal distribution at a level of significance of 4%. The RI medians varied from 70-71.5 for the dry-mix mortar and from 54.5-55 for the job-site mortar.

Thus, the ANOVA was proceeded, as shown in Table 10.

The tested model shows to be significant, when compared to the calculated and tabulated Fisher parameters. The coefficient of determination expresses that 64% of data variation is explained by the model adopted. It is also observed, as expected from the means analyses, that the moisture effect is not significant on the results of the Rebound Index. On the other hand, the type of mortar effect is highly significant, expressing the method sensibility to distinguish different superficial hardness, i.e. rendering mortars with different mechanical strengths in any moisture condition.

Figure 8 - **Estimation of the overall mean of the STS values for the type of mortar**

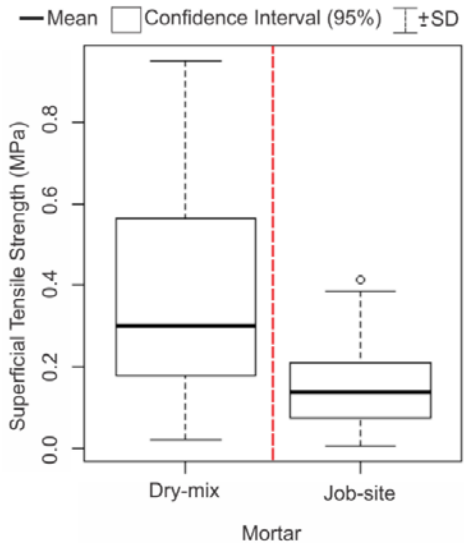


Figure 9 - **Histogram of frequency of the Rebound Indices for the M4 group of the dry-mix mortar**

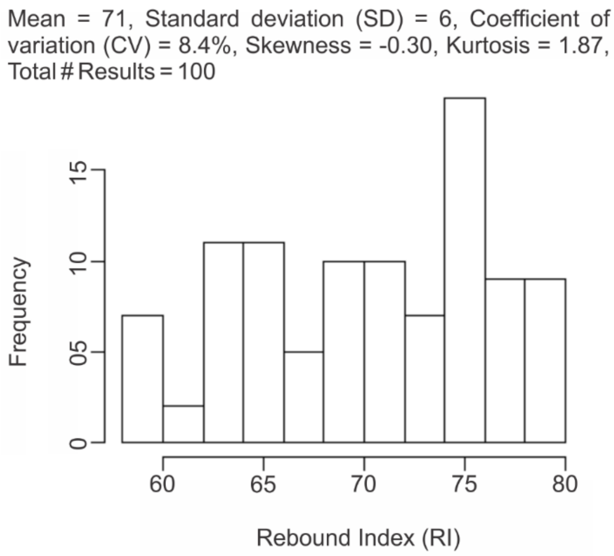


Table 10 - **ANOVA for the results of the rebound index**

Effect	Sun of squares	df	Mean square	Fcal	Ftab (F_α = 0.05)
Model	49127	7	7018	200.3	2.05
Moisture	57	3	19	0.545	2.64
Mortar	49016	1	49016	1399.2	3.88
Moisture x Mortar	54	3	18	0.515	2.64
Error (Residuals)	27746	792	35	-	-

Note: Coefficient of determination (R^2) = 0.64;
Correlation coefficient (R) = 0.80.

Figure 10 presents the estimation of the RI overall means in function of the types of mortar, confirming the mechanical strength superiority for the renders elaborated with dry-mix mortar.

According to RILEM hardness classification (Table 1), the renders of this research are classified as very hard (class E) and hard (class D), for the dry-mix and job-site mortars, respectively.

Bond Strength - BS

According to the K-S results (Table 9), as well as the visual analysis of the histograms, all the sets of bond strength values present normal distribution. The coefficient of variation was quite high with a minimum of 34% and the overall mean of 47%. Nevertheless, the acceptance values are considered once this type of destructive test is known as a variable (RAMOS *et al.*, 2012) due to the already discussed conditions to the STS test. No tendency to decrease the CV was noted when the renders were drier, as previously observed for the STS tests.

The ANOVA results are shown in Table 11.

The ANOVA results were similar to the ones obtained to STS. The model, also the factors analyzed type of mortar and moisture condition of the renders, presented to be significant. Additionally, it is noted that the interaction of the moisture and mortar factors is also significant. The most relevant factor of the BS results is the type of mortar. The Duncan test showed the 4 levels of moisture are distinct from each other in the two types of mortar. Figure 11 presents the representation of the overall mean estimation for the values of tensile bond strength, for the two mortars tested.

Finally, the boxplot representation was created in Figure 12, to represent the estimation of the overall mean of the BS results according to the type of mortar; showing the same tendency previously observed, i.e. superior results to the dry-mix mortar.

Figure 10 **– Estimation of overall means of the Rebound Indices according to the types of mortar**

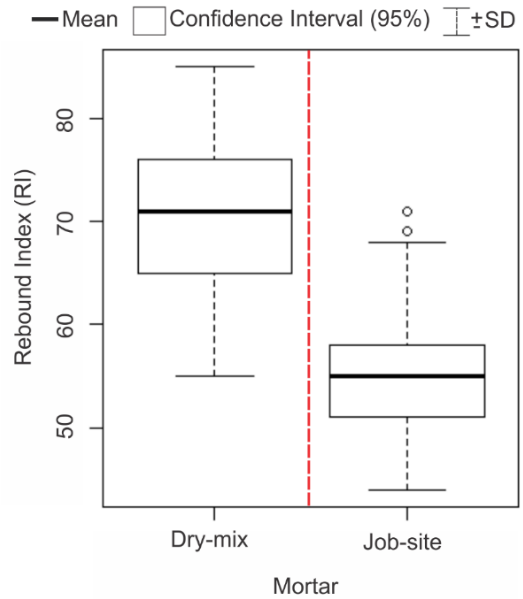


Table 11 **– ANOVA for the bond strength results**

Effect	Sun of squares	df	Mean square	Fcal	Ftab (F_α = 0.05)
Model	4.195	7	0.599	63.87	2.04
Moisture	1.939	3	0.646	68.9	2.64
Mortar	2.035	1	2.035	216.9	3.88
Moisture x Mortar	0.481	3	0.160	17.1	2.64
Error	2.702	288	0.009	-	-

Note: Coefficient of determination (R^2) = 0.61; and
Correlation coefficient (R) = 0.78.

Figure 11 – **Estimation of the overall mean values for the tensile bond strength in function of moisture: (a) dry-mix mortar; and (b) job-site mortar**

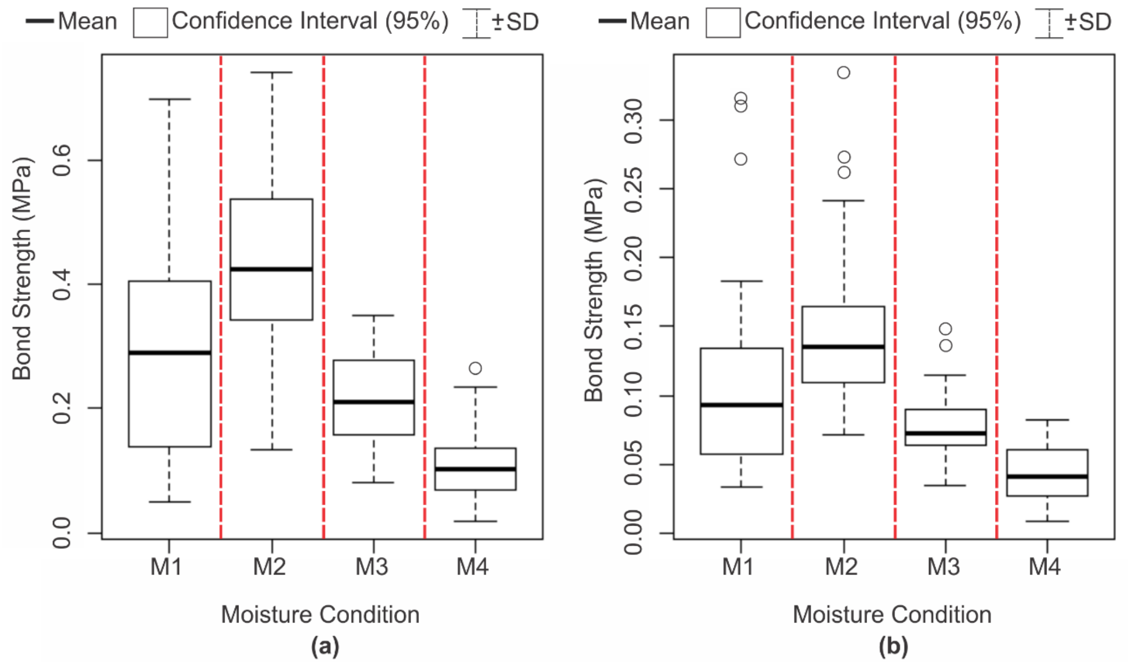
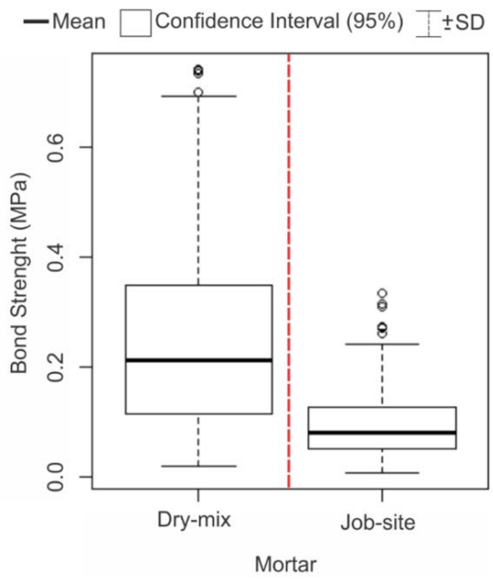


Figure 12 – **Estimation of the overall mean results of the tensile bond strength**



Correlation between tests

Attempts for the linear correlation among the different tests were carried out, verifying the coefficient of determination (R^2) and the Pearson Index. To do so, the means of the readings for each one of the tests in the same level of moisture variation were used. Table 12 summarizes the correlations obtained.

The rebound hammer test does not have a significant relation with the other tests, with considerably low values for the coefficient of determination. In part, this was expected, once the moisture effect was not significant for the RI, while the opposite happened for the other tests. The relation between the results of the superficial tensile strength and bond strength showed to be significant for the two mortars.

Table 12 **– Correlations between the tests methods used**

Mortar	Correlation	R^2	Linear equation
Dry-mix	RI x STS	0.00	-
	RI x BS	0.07	-
	STS x BS	0.87	Y = 0.5747x + 0.0559
Job-site	RI x STS	0.04	-
	RI x BS	0.00	-
	STS x BS	0.91	Y = 0.5835x + 0.0113

In Figure 13 the chart representations of the Pearson correlations are displayed, in an alternative manner of presentation, where the circles indicate the correlation through an index of colors and sizes, evidencing, in a clear way, the weak and strong correlations between the tests (the larger the circle and the darker the color the stronger the correlation between the variables).

In Figure 13 is possible to visualize that the rebound hammer test does not have a considerable linear correlation with the other tests, according to what was previously proved with the coefficients of determination. On the other hand, the BS and STS tests obtained Pearson indices of 0.93 and 0.95, for the dry-mix and job-site mortars, respectively, showing very strong linear correlations, according to Mukaka (2012).

Figure 14(a) shows the results of the superficial tensile strength and bond strength tests are directly proportional. There is also a parallelism between the two tendency lines of each mortar that are dislocated from each other. This fact indicates the type of mortar variation interferes little on this correlation and the data may be analyzed together in an only linear correlation (Figure 14(b)).

Therefore, the chart displayed in Figure 14(b) indicates once the results of bond strength are obtained, which is a test frequently conducted on site for the renders' control, it is possible to infer about the superficial strengths of these renders. This verification is valid, at first, for the mortars studied. It should be noted that in a previous study, Carasek *et al*. (2011) obtained a similar correlation with mortars prepared on site (two distinct proportions) and many conditions of application.

Moisture influence in the measurements conducted

Moisture was an influent factor in the STS and BS results, what was contrarily observed in the RI results. For the STS and BS case, the behaviors are similar. When the air-dried renders are tested (M2), they present the highest values, and as the moisture increases, the values abruptly decrease (drops higher than 70%, when the result obtained from the saturated renders are compared to the ones air-dried). Many studies have demonstrated a similar behavior related to the evaluation of other mechanical properties of concretes submitted to different moisture gradients (LAMOND; PIELERT, 2006). Guo and Waldron (2001) present an explanation for this phenomenon based on the combination of Griffith's fracture criterion and surface free energy theory. It is suggested that changes in strength during adsorption is correlated with surface free energy. When water is absorbed into the gel, the spreading pressure forces the gel surfaces further apart, resulting in a reduction in the Van der Waals forces between gel particles. This leads to a decrease in the surface free energy since the specific surface energy is proportional to the adhesive forces. Thus, using Griffith's criterion, the critical stress decreases as the amount of absorbed water increases. Moreover,, Galloway, Harding e Raithby (1979) argued that the presence of water in the concrete might cause a dilation of the cement gel, which results in a weakness in cohesion of the solid particles.

On the other hand, the oven-dry produced a reduction in the superficial and bond strengths, demonstrating that drying at high temperatures (100 ºC) generates a significant damage to the mortar's microstructure.

Figure 13 - **Correlations between the tests through the Pearson index: (a) dry-mix mortar; and (b) job-site mortar**

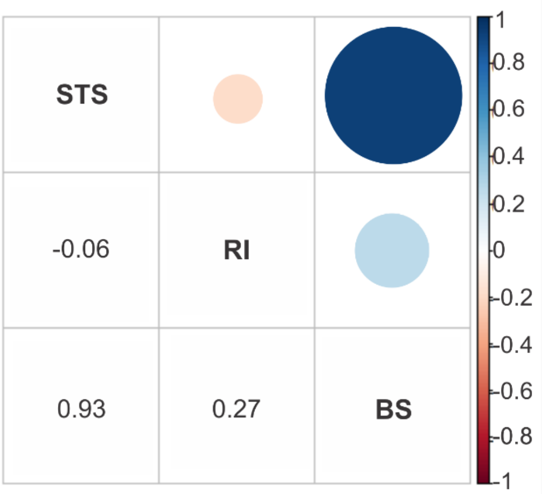
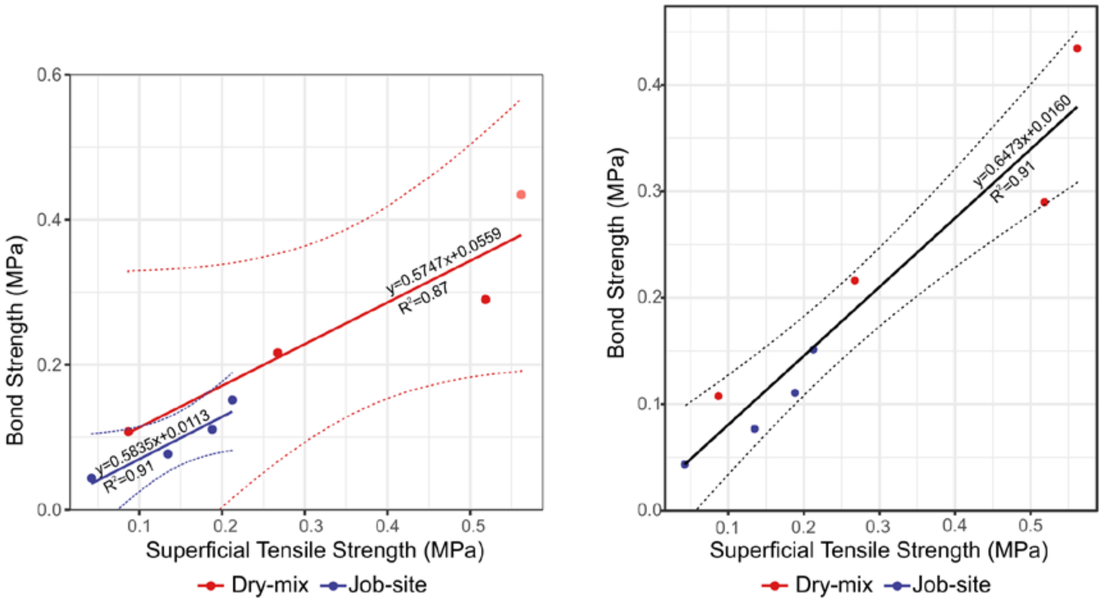


Figure 14 - **Tendency lines with the respective confidence intervals (95%) between STS and BS: (a) correlations obtained for the two mortars; and (b) all the results**



The verification of the moisture influence on these two tests creates the need to consider and measure the moisture content when the results are interpreted. A practical situation on site is the conduction of control tests for the renders applied on facades; if the moisture effect is not observed in these cases, a render may be rejected based on the tests conducted during the rainy period and accept the same renders when tested under dry weather.

Conclusions

The two tests to evaluate the superficial properties (STS and RI) were sensible to distinguish mortars with very different strengths, being approved for this kind of evaluation. In this research, the most significant effect in all the models tested (different tests) was the type of mortar.

The variation of the render moisture condition at the moment of the test was significant for the results of STS and BS determination. Tests carried out with the humid or saturated renders tend to present strength results much lower than the air-dried renders. The verification of the moisture influence creates the need to consider and measure this variable when the results are interpreted. In this regard, it is also advised that the accepted limits of bond (BS) and superficial (STS) strength established by standards must be dependent on the moisture, or else the standard must establish a moisture condition in which the test is performed.

These two tests have the same principle, the pull-out of a part of the render through direct traction, once the STS methodology derives from the BS and also present similar behaviors regarding the variability of the results (CV) and data normality. It was possible to obtain a significant correlation between these tests, with a high coefficient of determination; that indicates that once the results of the bond strength are available, it is possible to infer about the render superficial strength.

In the case of the pendulum rebound hammer, the render moisture effect at the moment of the test was not significant in the results. This verification, in addition to the low CVs obtained, besides the capability of distinguishing mortars with distinct mechanical strengths and the non-destructive feature of the test, indicates a great potential to utilize this test to control the render on site, especially its homogeneity.

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