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Methodology for evaluation of the influence of roughness and capillary absorption of ceramic blocks on the render's tensile bond strength

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Abstract

The literature indicates that it is difficult or even impossible to associate with strong statistical confidence the bond strength of a mortar coating with the properties of the ceramic block, such as roughness and water absorption. In this work, it is assumed that the variability in capillary water absorption and roughness, and the use of methods that provide differences in sampling area are key factors that make it difficult to model and obtain a proper correlation between these properties and the tensile bond strength of the render. Blocks with different porosities and roughness were used in the experimental program, and an original methodology was defined. Substrate properties showed high variability between blocks in the same batch, and in different regions of the same block. The proposed methodology allowed to obtain a significant correlation between substrate properties and the render's tensile bond strength.
Keywords: render, ceramic block, capillary absorption, roughness, tensile bond strength.

INTRODUCTION

Renders have the function of guaranteeing the leveling of the surface and providing protection to the masonry and the structure, in order to allow an adequate performance during its service life [1]. However, despite the technological advancement in the area, pathological manifestations in renders, such as detachment, are found in modern buildings [2], due to failures in the adhesion between the mortar and the ceramic substrate. The main mechanisms that explain adherence are chemical adherence and mechanical adherence. The first is defined by the laws of attraction and repulsion of atoms [3], such as van der Walls intermolecular forces and primary bonds, which in theory depend on the reactivity of each material [4]. This mechanism strongly assists in the adhesion between the materials since there is a chemical interaction between the atoms and/or molecules of the mortar and the substrate [5]. Mechanical adhesion, on the other hand, assumes that the adhesive material spreads over the surface pores and the roughness of the substrate, allowing, in the case of mortars, cement hydration products to penetrate inside them and generate interlocking [4, 6]. The adherence of a mortar depends mainly on its rheology and its granulometric composition, which define its spreading and water retentivity, in addition to the application technique and curing conditions [7, 8]. The characteristics of the substrate also strongly influence adherence and are a function of the clay composition and the sintering process to which the block was subjected during its manufacture, which defines the pore structure, capillary absorption, and roughness of the final product [9].

The substrate influences the bond strength of the render, mainly due to the mechanical interlocking mechanism. There is a consensus in the literature that one of the properties with the greatest influence on the bond strength is the capillary absorption of the blocks, generally evaluated from the initial rate of absorption (IRA) test [6, 10-12]. The absorption of water is related to the dimensions and the pore volume of the ceramic [12] and depends on the sintering process of the blocks. As the firing temperature increases, the internal porosity decreases. The most significant changes occur at temperatures between 700 and 1100 °C [9, 13]. When the mortar comes into contact with the substrate, part of the mortar water is transferred to the interior of the block, and the reverse can also occur, where the water returns to the mortar after the cement hydration begins, a process that tends to impair adherence to the interface [11]. The amount of water that migrates from the mortar to the block depends on the capillary absorption of the substrate and the amount of water available in the mortar [7, 12]. The water transported from the mortar to the block brings the anhydrous cement particles closer to the interface, promoting a less porous transition zone and facilitating the penetration of hydration products into the pores of the substrate, but in excess can cause shrinkage of the mortar and increased micro-cracking in this region [6]. The influence of block absorption on the render's bond strength is not yet adequately clarified, as several factors simultaneously influence this property, whether intrinsic, such as the composition of the clay and the sintering process, or extrinsic, such as the properties of the mortar and the characteristics of the application process [6, 7, 9, 12-14]. Several authors question the effectiveness of the IRA test, since it analyzes only the first minute of contact of the ceramic sample with water, proposing the determination of an absorption curve over time [15, 16].

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Both the Brazilian standard ABNT NBR 15270-2 [17] and the British standard BS EN 771-1:2011 [18] specify that the capillary water absorption test must be carried out on one side of a block, which is immersed 3 mm in water. This procedure determines a single capillary absorption value for a given block. Usually, the test is performed on a few blocks and the average between the values is used to calculate the capillary coefficient, which is extrapolated to the batch. In the ABNT NBR 15258 [19] and BS EN 1015-12 [20] standards, the area of the block used to determine the bond strength of a rendering mortar corresponds to a small area of circular shape, with a diameter of 50 mm. Starting from the premise that the surface of red ceramic blocks is heterogeneous and that each region of the same face of the block can show significant variations in water absorption, the differences between the regions where both the capillary test and the bond strength test are performed may prevent the correlation between the results of these two tests. Another property that influences the bond strength is the surface roughness of the substrate. Every material has a roughness, depending only on the scale of analysis and observation [21]. Fig. 1 shows the surface of a red ceramic block, identifying, on a micrometric scale, its topography variations (image obtained with a Zeiss Smartzoom 5 digital microscope). When evaluating the roughness on a micrometric scale or less, the surface of the block, which under macroscopic analysis has a smooth appearance, starts to show roughness variations. The roughness is determined in the order of micrometers, using several parameters for its characterization, the most common being the roughness coefficient Ra [22]. Roughness is directly influenced by the characteristics of the material and its manufacturing process. The shape and dimensions of the roughness influence the quality of the adhesion, considering that they generate different areas of contact between the materials [23]. When analyzing the interface between a block and a mortar, for good adhesion to occur, it is necessary that the block has a rough, compatible surface with the rheological properties of the mortar, which must mold itself on its surface and generate the mechanical interlock between the two materials [5]. For a given mortar, as the roughness of the block increases, the bond strength tends to increase. A greater roughness generates a greater contact surface and, if that surface is filled with cement grains and mortar filler, the adhesion increases.

There are many uncertainties regarding how the substrate roughness can be related to the bond strength. Roughness is formed through processes that generate irregular surfaces, that is, there is no way to guarantee that the entire surface maintains the same pattern and that this pattern can be easily reproduced [23]. Studies indicate that with the increase in roughness there is an increase in capillary strength once the increase in roughness changes the contact angle between materials [24]. However, there are controversies about the influence of this property on adherence, one of the main causes being the lack of consensus on the method to be adopted for its determination. Almost all of the studies already carried out were developed with two-dimensional analysis technologies, based on the determination of the roughness along a line drawn on the surface of the substrate, which does not allow an adequate determination of the roughness variation along the entire face of the block [18]. The ceramic blocks have a heterogeneous structure due to the processes intrinsic to the raw material, manufacturing, and firing of the material, with indications that the same block may present different roughness and capillarity when analyzed in different areas. Recently, authors have started to adopt new technologies that allow the three-dimensional analysis of the roughness [25], allowing a better evaluation of the roughness and expanding the understanding of the relationship between the properties of the substrate and the adhesion.

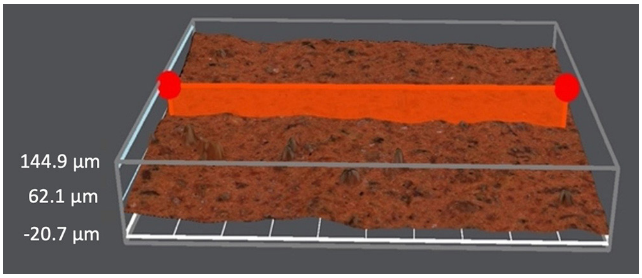

Figure 1: Visualization of the roughness of a surface section of a red ceramic block on a micrometric scale.

Although several studies relating the properties of the mortar with the water absorption of the substrate and the roughness are frequently mentioned in the literature, few of them evaluate the correlation between these properties of the substrate and the adhesion, and it is still not possible to model its behavior. The studies that present results of the evaluation of the bond strength of renders present a high variability, invariably impeding the statistical validation of the results [1, 26]. In this research, it is assumed the hypothesis that the variability of water absorption by capillarity and roughness of the ceramic block, together with the methods used that provide differences in the sampling area for carrying out the tests to determine these properties, are factors that make it difficult to model and obtain an adequate correlation between these properties and the bond strength. Thus, this research aims to estimate the variability of roughness and capillary absorption of red ceramic blocks and to propose a methodology that allows relating the properties of the substrate with the bond strength of a mortar.

MATERIALS AND METHODS

The experimental program consisted of: execution of renderings on ceramic blocks with different properties; definition and execution of methods for characterizing the capillarity and roughness of the blocks; determination of the bond strength of the renders; and critical evaluation of the influence of these substrate properties on the render's bond strength. The mortar used was composed of cement, natural quartz river sand, and quartz powder filler. The proportion used was 1:3 (cement:sand) in mass, with a w/c (water/cement) ratio of 0.46, and consistency of 260±5 mm, adjusted using a polycarboxylate-ether-based superplasticizer. As there was no substrate preparation (roughcast), a 5% replacement of sand with quartz powder was used, in order to provide enough mechanical interlock at the interface. The mortar mixture was carried out in a bench mortar mixer and followed the procedures of the Brazilian standard ABNT NBR 16541:2016. The mortar characterization tests were carried out in triplicate.

A cement CP II Z-32 (equivalent to the American Type IP - Portland-pozzolan cement, with 5.8% of pozzolanic material) was used, whose characteristics are shown in Table I. The granulometric distribution of the cement was performed by laser diffraction, in a particle size analyzer (S3500, Microtrac), using isopropyl alcohol as a dispersant, and resulted in D_{10}=6.67 μm and D_{90}=36.02 μm. Table II shows the characteristics of the quartz powder. The quartz powder granulometric distribution was also carried out by laser diffraction, with previous dispersion in water with superplasticizer and ultrasound at the power of 40 W for 60 s, resulting in D_{10}=1.8 μm and D_{90}=12.4 μm. Natural fine aggregate (quartz) with grains passing through the 4.8 mm sieve was used. Table III shows the characteristics of the fine aggregate. Fig. 2 shows the granulometric curves of cement, quartz powder, and sand.

The substrates used were structural red ceramic blocks, with modular dimensions of 15x20x45 cm. In order to produce substrates of the same composition, but with different characteristics of water absorption and roughness, raw blocks were collected from local pottery, from the extrusion of the same batch of clay. In the laboratory, they were sintered in a muffle, firing the samples at 800, 900, or 1000 °C (which resulted in three groups of blocks, called batch A, B, and C, respectively). The firing occurred with a heating rate of 150 °C/h and a holding time of 10 h, after which they were naturally cooled. Firing temperature and the heating rate were chosen based on preliminary tests and several studies that used a similar methodology [13, 27, 28]. The bibliography indicated that the bond strength tests of mortar coatings have a high standard deviation [1, 26], with coefficients of variation reaching 100%, which generally makes it difficult or even impossible to associate them with statistical confidence to the mortar and substrate properties. In this research, we sought to evaluate the influence of the capillarity and roughness variability of the ceramic substrate in this deviation, from the determination of the variations in the results of these properties when the tensile test is performed in different locations of the same block or when it is performed in different blocks of the same batch (from the same clay batch and from the same firing process). To evaluate the influence of capillary absorption and roughness at each test site in the same block, they were cut into smaller pieces (specimens) of 5x5 cm (Fig. 3). Such a procedure allowed the determination of the capillarity and the bond strength in each specimen obtained. The roughness of specimens from each tested block was also determined. A total of 126 specimens of 5x5 cm were tested for each batch.

To allow the determination of the effect of roughness on adhesion without the simultaneous action of capillarity, the specimens of each batch were divided into two groups, one without application of water repellent, and the other with the application of three coats of an oligomeric siloxane-based water repellent, with a high capacity of absorption in the substrate, which inhibited 99% of the capillary absorption of the pieces (these specimens were called AWR, BWR, and CWR, and corresponded to 50% of the specimens of the original batches A, B, and C). Thus, the adherence of the mortar was influenced simultaneously by the capillarity and the roughness in the substrates without water repellent

Table I - Physical, mechanical, and chemical characteristics of cement.

Fineness			Setting time (min)		Compressive strength (MPa)			MgO (%)	Mean SO_3 (%)	Mean fire loss (%)	Insoluble residue
Blaine (cm^2/g)	200# (%)	325# (%)	Initial	Final	3 days	7 days	28 days				
4100	3.4	10.4	290	380	27.6	31.6	-	3	2.4	5.8	-

Table II - Typical and referential characteristics of quartz powder.

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Loss on ignition, 850 °C	Bulk specific gravity (g/cm^3)
99.66%	0.15%	0.04%	0.01%	0.25%	2.65 to 2.90

Table III - Characteristics of fine aggregate.

Unit weight[a]	Bulk specific gravity[b]	Air-void content[c]
1589 kg/m^3	2583 kg/cm^3	38.50%

[a]ABNT NBR NM 45:2006; [b]ABNT NBR NM 52:2009; [c]ABNT NBR NM 45:2006.

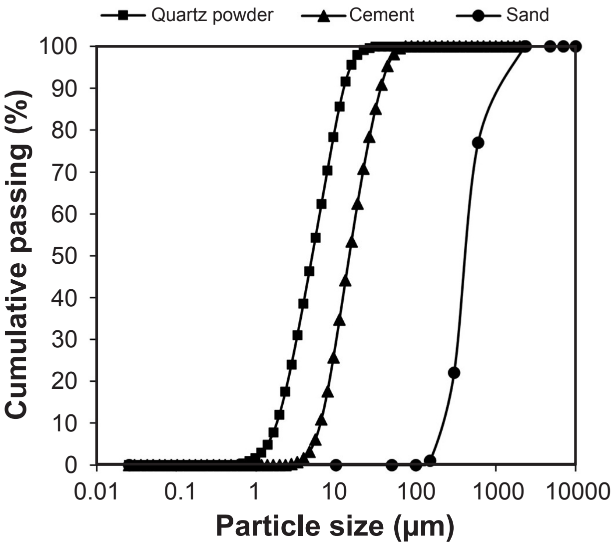

Figure 2: Particle size distribution curves of cement and aggregates.

application and only by the substrate roughness in the specimens with water repellent application. It was assumed that the water repellent, as it does not form a film, did not significantly alter the roughness of the substrate. The capillary water absorption test was performed according to the RILEM TC116 PDC (1999) method [29], using measurement times of 1, 2, 5, 10, 30, and 60 min. This method determines the capillary coefficient based on a linear equation associated with the entire capillary absorption time of the substrate, being more accurate than using the IRA method. Capillary absorption curves were performed to determine each capillary coefficient, as shown in Fig. 4. From the curve that represented the results of the mass increase of the specimen (Fig. 4a), linear trend lines were determined for the capillary absorption regime and saturation regime (Fig. 4b), with the objective of identifying the time in which a change in the phenomenon that governs water penetration occurred, in a procedure similar to that proposed for concrete [30]. The first straight line, which begins at the origin of the axes, represents capillary absorption. The capillary absorption coefficient was calculated from its slope and the thickness of the analyzed sample, in g/(cm^2.h$^{1/2}$).

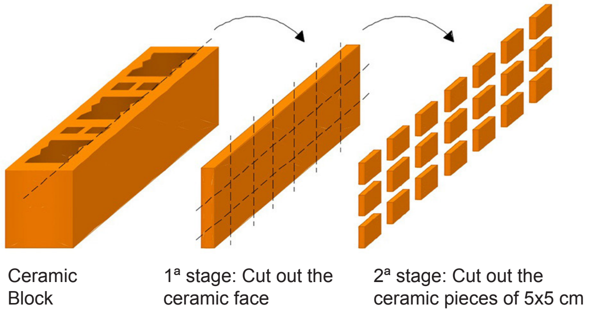

Figure 3: Representative scheme of cutting ceramic substrates in 5x5 cm specimens

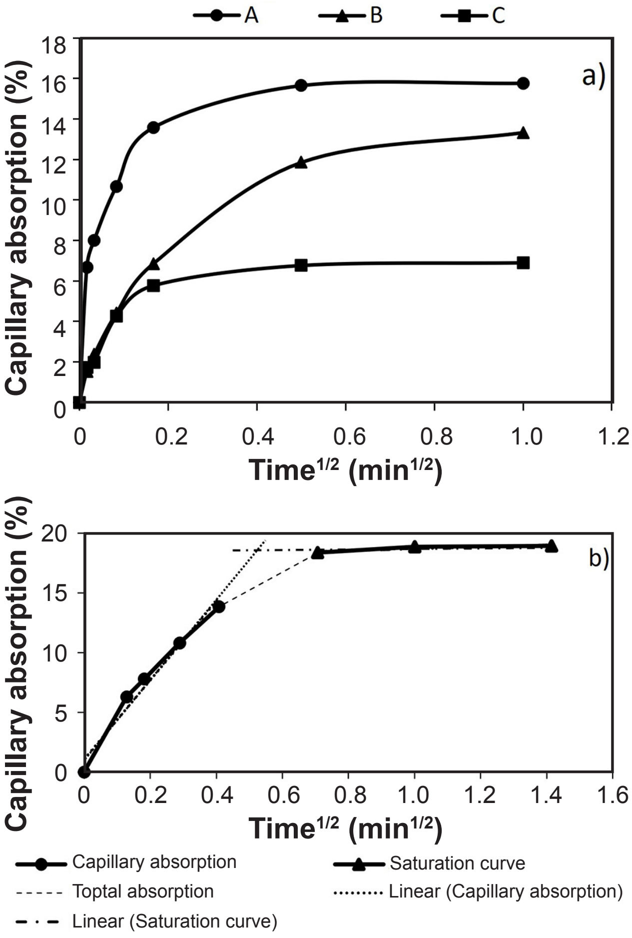

Figure 4: Capillary absorption graphs of substrates: a) typical water absorption curve for each batch; and b) example of the determination of a straight line corresponding to the capillary absorption of a specimen, based on the water absorption curve.

The surface roughness (Ra) of each specimen was determined by three-dimensional laser profilometry (Galileo AV 300+, Starrett), using the methodology applied in the literature [31]. Three specimens from each batch were tested. To carry out the test, the samples were previously dried and cleaned in order to eliminate loose particles and minimize the reading error. After the capillarity and roughness absorption tests, data were statistically analyzed using the analysis of variance (ANOVA) technique at a significance level of 0.05, in order to verify the existence of statistically significant differences between the results within the same block face, within the same firing temperature (same batch), and between different firing temperatures (different batches). For molding of the renders, a circular shape (4 cm diameter) metal template with 2 cm height was used. These dimensions were defined based on the size of the substrate that received the application of the mortars (5x5 cm). The renders were molded in an air-conditioned room at 23±2 °C and relative humidity of 60%±5%. The mold was adjusted in the center of the ceramic piece, which was in dry condition and filled with mortar. In order to simulate the impact energy

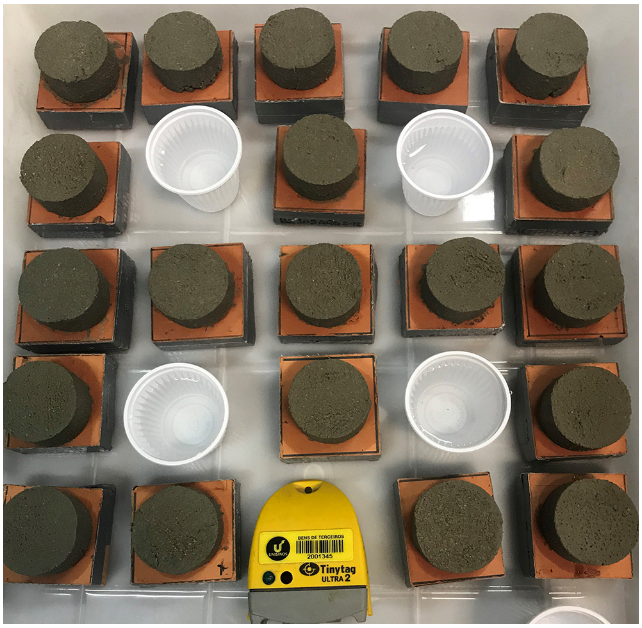

Figure 5: Image of mortars molded on the ceramic specimens.

produced when applying the mortar manually, the Proctor test socket was used, with a drop height of 45 cm. This height was specified based on previous studies [32]. The specimens were kept in a saturated environment at 23±2 °C for 28 days (Fig. 5). The tensile bond strength of the renders to their substrate was determined according to the procedure specified by the Brazilian standard ABNT NBR 15258 [19] (equivalent to EN 1015-12) [20].

RESULTS AND DISCUSSION

Fig. 6 shows the average results of water absorption for the ceramic blocks from batches A, B, and C. The firing process at different temperatures generated different blocks in terms of open porosity, which indicated that the objective of generating blocks with the same chemical composition, but with different porosities, was achieved. The capillary absorption of the blocks, which is the mechanism responsible for the suction of the mortar water immediately after its application, was determined in three levels among: specimens from the firing processes carried out at different temperatures (batches A, B, and C); specimens from the firing process carried out at the same temperature (in the same batch); and specimens from different regions, but on the same face of a block.

The analysis of variance of the mean values of water absorption by capillarity among batches (Fig. 7) proved that there is a statistically significant difference between the means. The determination of water absorption by capillarity performed on the ceramic specimens that received the application of the water repellent (AWR, BWR, and CWR specimens), demonstrated inhibition of capillary absorption of about 99%, thus achieving the objective of producing substrates with virtually no capillary absorption, where the influence of surface roughness on adhesion can be determined

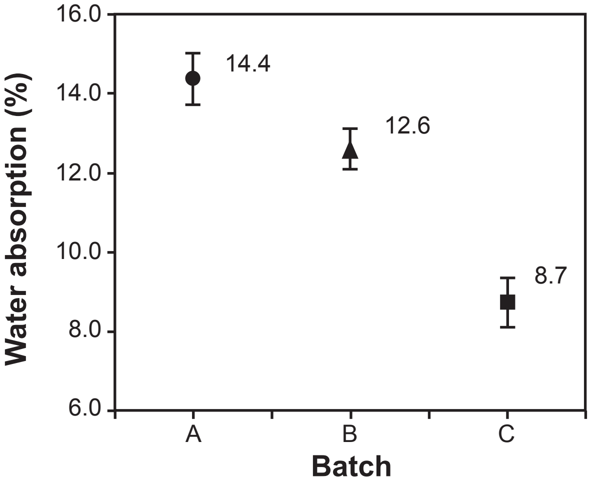

Figure 6: Total water absorption for the three batches (mean and coefficient of variation).

without the joint influence of capillarity. In the analysis of the results, it was considered that in these specimens the capillary absorption was null. For each block, the capillary coefficient was calculated by averaging the results of all specimens corresponding to this block. Based on the hypothesis that block heterogeneity implies differences in capillarity along different regions of the same block face, a capillary analysis of specimens from the same block was also performed, which is not normally considered in the literature. To exemplify the observed behavior, Table IV shows the capillary coefficients between blocks and capillary coefficients measured on the same face of the same block (all from batch C). Although the mean capillarity values were significantly different between batches, it was observed that there was high variability between the capillary coefficients of the same batch and that the variability was also expressive when specimens from different regions of the same block were compared. From the evaluation of capillary absorption, it was found that even in blocks manufactured from the same clay, same manufacturing process, and the same firing process, there was a significant difference in the results of capillarity. When carrying out the mortar adhesion test in a given region of block surface, adhesion is influenced by the local capillarity and not by the average capillarity of the block. In the example presented for batch C, it was observed that the capillarity at the region of the adhesion test varied between 0.47 and 1.30 $g/(cm^2.h^{1/2})$ and the value adopted for capillarity, usually determined by contact of water with the entire surface of the block (as specified by the Brazilian standard ABNT NBR 15270-2:2017 [17], similar to BS EN 771-1:2011 [18] and ASTM C67 [33]), was close to 0.6 $g/(cm^2.h^{1/2})$. Consequently, the comparison between the two parameters tends to be made with a capillarity that does not correspond to the surface where the bond strength is determined.

Another factor that highly influences the bond strength of the mortar is the roughness of the substrate. In order to carry out a quantitative analysis, the roughness coefficients (Ra) of substrates were determined by means of three-dimensional

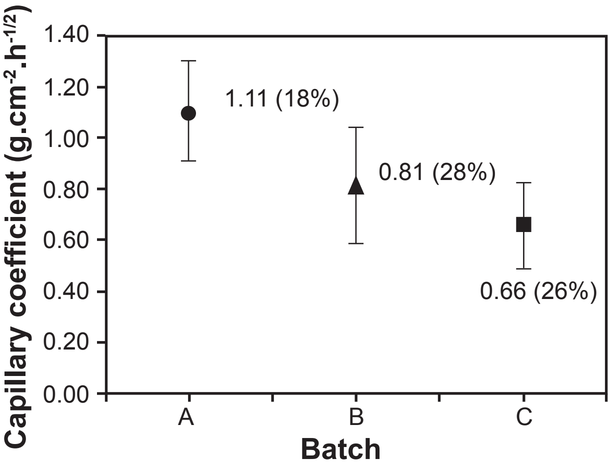

Figure 7: Capillary coefficient of specimens from each batch (mean and coefficient of variation)

Table IV - Capillary coefficients and their variations, g/(cm^2.h$^{1/2}$), in blocks of batch C.

Capillary coefficient	Variation between blocks	Variation between different points of the same block
Lowest value	0.47	0.47
Highest value	1.30	0.72
Average	0.66	0.59
Standard deviation	0.17	0.19
Coefficient of variation	26%	32%

laser profilometry, a method that offers greater confidence compared to the use of two-dimensional surface roughness testers [18]. The average results of the roughness parameter Ra for batches A, B, and C were 1.25, 0.96, and 0.78 µm, respectively (Fig. 8). ANOVA proved that all batches had significantly different roughness among themselves, that is, it was possible to produce blocks from the same ceramic mass and different firing cycles, with different surface roughness. The coefficients of variation associated with roughness were lower than those observed in capillarity. Part of this difference in variability was associated with the methods used. In this respect, it is highlighted that the method used to acquire the three-dimensional point cloud from which the roughness is calculated is automated and presents high reproducibility of results, unlike the method used to determine capillarity, which presents higher operational interference.

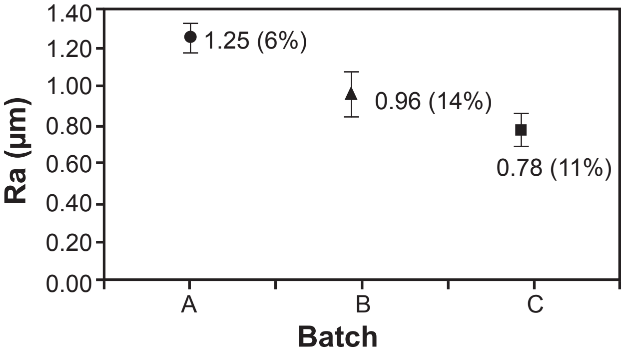

Figure 8: Mean roughness (Ra) and standard deviation of each batch.

Table V shows the roughness parameter Ra determined in different regions on the same face of a block from batch B and between different blocks from batch B. The roughness parameter Ra of batch B varied 14% between blocks from the same batch, and 15% when determined in different regions of the same face of a sampled block. The coefficients of variation of the surface roughness in the same block had the same order of magnitude as the variation in the roughness between blocks of the same batch, which indicated that variations in clay composition and intrinsic processes of the manufacture of ceramic pieces, such as the extrusion process, resulted in blocks with high heterogeneity of roughness. The differences in roughness found in the same block require that the test be carried out in the same region of the adhesion test if it is intended to relate the two parameters. However, in the majority of research works, roughness is determined by means of a two-dimensional capture of points on the surface along a straight line with millimeters of extension and is usually extrapolated for the entire block, which generates a Ra that may not be representative of the roughness of the entire surface. In the example of batch B, the coefficient Ra in the region of the adhesion test (determined by three-dimensional mapping, on a 100 mm^2 surface) varied between 0.593 and 1.307 µm. If it was determined in just one block, the value adopted for the roughness would be 0.77 µm and if an average value was adopted for the batch, it would be 0.95 µm. In addition, if Ra is determined by a two-dimensional method, it may not be representative of the specimen's roughness [18].

Table V - Roughness parameter Ra and its variation (µm) in blocks from batch B.

Roughness	Variation between blocks	Variation between different points of the same block
Lowest value	0.593	0.593
Highest value	1.307	1.026
Average	0.950	0.770
Standard deviation	0.131	0.114
Coefficient of variation	14%	15%

The results of the characterization of the rendering mortar are shown in Table VI. Although mortar tensile bond strength is not directly dependent on the mechanical properties of the mortar, it is worth pointing out that high dynamic elastic modulus values could impact the rendering durability and should be evaluated by complementary tests [41, 42]. The adoption of a mortar with higher cement consumption (which resulted in higher compressive strength and modulus of elasticity) was due to the need to ensure adherence without the use of sand and cement undercoat, to better evaluate the influence of the substrate.

Table VII summarizes the average mortar bond strength and the characteristics of the blocks of each batch. The variability of capillarity and roughness explained, in part, the variability also found in the bond strength and added itself to the influence of other factors. The variability of the bond strength was high and presented the same order of magnitude in all substrates. These values were consistent with those found by other authors [1, 26, 43], who frequently criticize the high variability of these tests.

The average bond strengths and respective coefficients of variation were obtained from the 252 specimens tested with and without the application of water repellent and are shown in Fig. 9. For the graph shown in Fig. 9 and the following ones, the values of capillary absorption and bond strength obtained in each 5x5 cm specimen were used and, whenever possible, with their respective roughness. The blocks from batch A showed the highest values of bond strength for both groups. This fact was associated with the higher absorption by capillarity and greater roughness of substrate found in the specimens of this batch. The substrates without application of water repellent showed higher bond strength compared to the substrates where the water repellent was used, demonstrating that the water absorption by the substrate has a strong influence on adhesion. The application of water repellent and consequently the elimination of the capillary absorption effect caused a 4% drop in bond strength in blocks of batch A, 16% in blocks of batch B, and 36% in blocks of batch C. The ANOVA proved that there were significant differences between the results of bond strength between the batches. However, when comparing the bond strength between substrates A, B, and C and the substrates AWR, BWR, and CWR, ANOVA indicated a significant difference only in batch C, where the elimination of capillary absorption by the application of the water repellent significantly reduced the adhesion.

Table VI - Mortar characteristics.

Property	Standard	Mean±standard deviation
	Fresh state	
Consistence	NBR 13276 [34]	265 mm
Water retentivity	NBR 13277 [35]	96%
Bulk density	NBR 13278 [36]	2118 kg/m^3
Air content	NBR 13278 [36]	13%
Flexural strength	NBR 13279 [37]	7.1±0.3 MPa
	Hardened state	
Compressive strength	NBR 13279 [37]	30.8±0.4 MPa
Shrinkage	NBR 15261 [38]	0.57±0.06 mm/m
Mass variation	NBR 15261 [38]	2.91%±0.15%
Bulk density	NBR 13280 [39]	2046±33 kg/m^3
Dynamic modulus of elasticity	NBR 15630 [40]	26067±551 MPa

Fig. 10 shows the correlation between the properties of the evaluated substrates and the bond strength. In order to allow better visualization of the results, two graphs were elaborated, relating the adherence to capillarity (Fig. 10a) and the adherence to roughness (Fig. 10b). The regression line shown in Fig. 10a, obtained by the association between the properties of the samples of batches A, B, and C and the bond strength, was a function of the simultaneous action of water suction by capillarity and the influence of roughness on the spreading of the mortar over the block surface. In the AWR, BWR, and CWR specimens, in which the substrate was prepared with the water repellent, the capillarity effect can be neglected. Fig. 10b shows that the differences in adherence between the batches with water repellent and the batches without water repellent were a function of the capillarity. It was possible to determine a regression line with a high correlation coefficient and a satisfactory angular coefficient for the two properties of the substrates. As shown in Fig. 10a, in substrates without water repellent (batches A, B, and C), the blocks with the highest capillary coefficient resulted in higher values of bond strength, as indicated by the literature. The suction of water by the substrate allows the movement of water from the mortar to the substrate [44],

Table VII - Mean, standard deviation (SD), and coefficient of variation (CV) of water absorption by capillarity and roughness of the ceramic blocks and bond strength of mortar/block set.

Batch	Capillary absorption (g.cm^{-2}.h$^{-1/2}$)			Roughness Ra (μm)			Bond strength (MPa)		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
A	1.11	0.20	18%	1.25	0.08	6%	0.33	0.18	53%
B	0.81	0.23	28%	0.96	0.11	15%	0.26	0.16	59%
C	0.66	0.17	26%	0.78	0.08	11%	0.24	0.15	62%
AWR	0	0	0	1.25	0.08	6%	0.32	0.25	77%
BWR	0	0	0	0.96	0.11	15%	0.23	0.13	57%
CWR	0	0	0	0.78	0.08	11%	0.18	0.10	56%

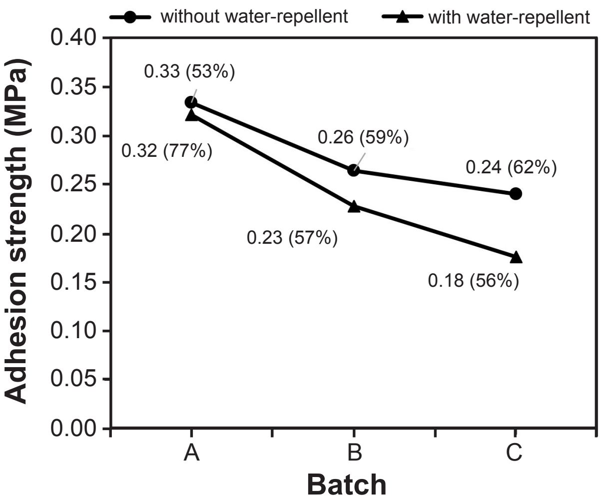

Figure 9: Mean tensile bond strength (CV) of the renders with and without water repellent.

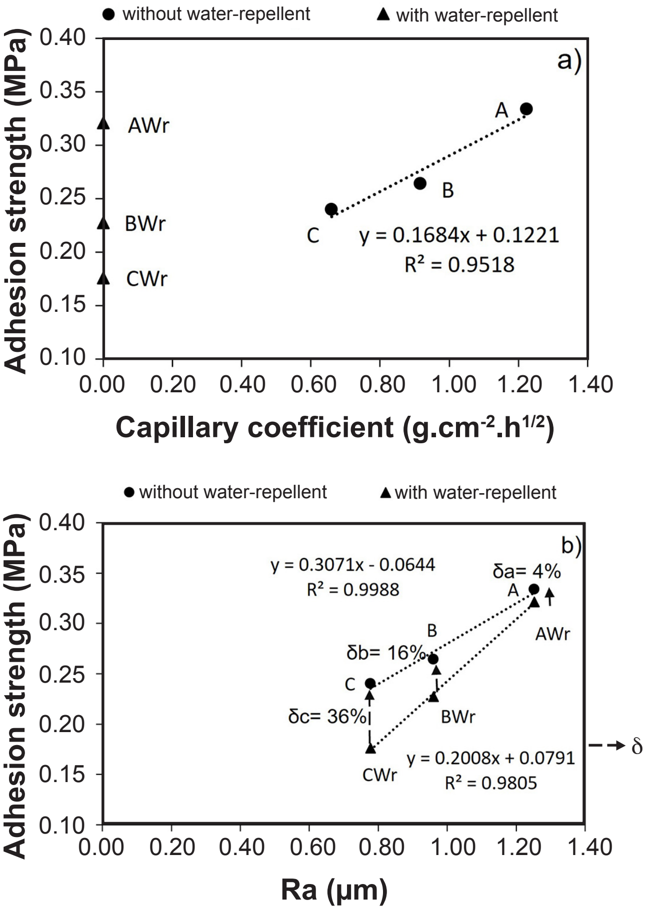

Figure 10: Comparison between adhesion strength as a function of surface roughness and capillary absorption: a) bond strength as a function of the simultaneous action of capillarity and roughness (batches A, B, and C) and without the action of capillarity (batches xWR); and b) bond strength as a function of block roughness (batches xWR) and simultaneous action of roughness and capillarity (batches A, B, and C).

allowing the migration of hydration products to the valleys and surface pores of the substrate, which increases the chemical and mechanical adhesion. However, capillarity and roughness are acting simultaneously in these blocks, which, under these conditions, are directly proportional properties. Regarding the substrates in which the capillary action was eliminated (AWR, BWR, and CWR, positioned on the abscissa axis), it is clear that, even without the capillary action, there were variations in the bond strength. However, as there was no simultaneous action of capillarity and roughness, the bond strength was lower.

Fig. 10b shows the bond strength obtained as a function of the substrate roughness (straight line with the xWR batches) and the contribution that capillarity provided for the increase of this resistance. As the roughness increased, the bond strength also increased. In blocks with water repellent, where the porosity did not influence adherence, the increase in roughness from Ra=0.777 μm (average roughness of the blocks in the CWR batch) to Ra=1.252 μm (average roughness of the blocks in the AWR batch) provided an increase in strength from 0.24 to 0.33 MPa. The linear equation that related the parameters had a coefficient of determination r^2=0.999, and an angular coefficient of 3.25, showing a strong relationship between the parameters. In substrates where no water repellent was used, there was an increase in bond strength, compared to those with water repellent, on the order of 36% in blocks of batch C, decreasing up to 4% in blocks of batch A. In blocks with lower roughness (samples from batch C), the contribution of capillarity to the bond strength was significant, but as the roughness increased, the increase in resistance due to the joint action of capillarity was lower.

Based on the experimental program carried out, it was concluded that, when determining the roughness, the capillary absorption, and the bond strength in the same position of the block, and using appropriate test methods for the comparison between properties, it is possible to obtain significant relationships between the tensile bond strength and the properties of the substrate. Despite the high coefficients of variation obtained, the correlations between the bond strength, capillary coefficient, and roughness showed a good linear fit and high coefficient of determination (r^2 between 0.95 and 0.99), which indicated a good correlation between the results. It is proposed that the procedures for characterizing the capillary absorption and roughness of the ceramic substrates, as well as the determination of the bond strength of renders, be carried out in the same analysis area and that methods that are reliable and compatible with each other be used, which allow the determination of statistically significant correlations between these properties.

CONCLUSIONS

The absorptions of water by capillarity of blocks of the same batch, manufactured from the same clay, the same manufacturing process, and the same firing process, using the method specified by RILEM TC116 PDC, presented statistically significant differences. This behavior was repeated when the surface of the same block was divided into smaller areas and capillarity was determined in each region, showing that the heterogeneity of the ceramic and their firing process provided significant changes in capillarity in different regions of the same block. The variability of roughness in red ceramic blocks, determined by means of a three-dimensional laser profilometer, was statistically significant, resulting from the heterogeneity of the clay and the production processes of the block. There were significant differences between the roughness coefficients Ra determined in blocks of the same batch and also when they were determined in different regions of the same block. The high variability of the results of the test of tensile bond strength of a render, according to the Brazilian standard ABNT NBR 15258, was justified by the variability of the properties of the ceramic block added to the variability from the mortar and its application process, in addition to the bond strength procedure itself. When trying to establish a correlation between the adhesion and the substrate properties, in addition to these factors, it must also be considered that usually the tests are performed on different areas of the substrate and using test methods that present high variation in their results. The simultaneous interference of these factors prevents significant correlations between the referred properties to be obtained. Using the test methods adopted in this research and performing all tests in the same region of the block, it was possible to identify the contribution of each property of the substrate on the tensile bond strength of the mortar. In the mortar and substrates evaluated, the increases in both roughness and capillarity were directly proportional to the increase in tensile bond strength. In all batches, the influence of roughness was more significant than that of capillary absorption. In specimens with greater roughness, the contribution of capillarity to the tensile bond strength was lower.

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