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Evaluation of the adherence of ceramic tiles applied as facade lining

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ABSTRACT

Among the pathological problems that can occur in ceramic tile, the loss of adherence is the most serious due to the risk of causing accidents should they fall and the repair costs it would entail. The purpose of this work is to evaluate the influence of the properties of different ceramic tiles, adhered with two types of mortar and subjected to three different curing conditions (established by the ABNT 14.081-4:2012 standard), with regard to the adherence of the lining system. Once a global analysis of the results was carried out, it was observed that the type of curing is the variable that shows the most significant influence on the adherence resistance, followed by the type of mortar, with the ceramic tile exercising little influence.
Keywords: adherence; ceramic tile; mortar.

RESUMEN

Dentro de las manifestaciones patológicas que pueden ocurrir en azulejos de cerámica se encuentra la pérdida de adherencia considerada la más seria debido a los riesgos de accidentes por el efecto de las caídas y el costo de la reparación. Este trabajo tiene como objetivo evaluar la influencia de las propiedades de diferentes placas de cerámica aplicadas con dos tipos de mortero de pega y sometidos a tres diferentes condiciones de curado (establecidas por la norma ABNT 14.081-4:2012) en la resistencia de adherencia del sistema de revestimiento. Se observó que el tipo de curado es la variable que presenta la influencia más significativa en la resistencia de adherencia, seguida por el tipo de mortero de pega, ya que el azulejo de cerámica ejerce poca influencia una vez hecho un análisis global de los resultados.
Palabras Clave: adherencia; azulejo de cerámica; mortero de pega.

RESUMO

Dentre as manifestações patológicas que podem ocorrer em revestimentos cerâmicos os descolamentos são considerados as mais sérias, devido aos riscos de acidentes em decorrência da queda de placas e por seu custo de reparo. Este trabalho tem como objetivo avaliar a influência das propriedades de diferentes placas cerâmicas aplicadas com dois tipos de argamassa colante e submetidas a três diferentes condições de cura (estabelecidas pela norma ABNT 14.081-4:2012) na resistência de aderência do sistema de revestimento. Observou-se que o tipo de cura é a variável que apresenta influência mais significativa na resistência de aderência, seguida pelo tipo de argamassa colante, enquanto a placa cerâmica exerce pouca influência em uma análise global dos resultados.
Palavras-chave: aderência; revestimento cerâmico; argamassa colante.

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1. INTRODUCTION

Among the pathological problems that could occur in ceramic lining, the ones that stand out are: the detachment of the tiles, splitting or cracking, efflorescence, and the deterioration of the joints (Campante and Baía, 2008). Among these, the detachment of the ceramic tiles is considered the most serious due to the risk of accidents as consequence of the tile or parts of it falling, as well as the repair costs this could entail (Campante and Baía, 2008; Mansur, 2007).

A main characteristic of the detachments or separations is the loss of adherence of the ceramic tiles with the substrate or the mortar, which occur when the tensions of the ceramic lining exceed the adherence capacity of the connections of these layers (Barros and Sabatini, 2001). External factors such as thermal shock, directed rain, solar radiation, and humidity are the ones that exercise the greatest influence in the degradation of the facade lining system (Antunes, 2010).

Temperature variation is an expressive degradation agent of the ceramic facade linings (Consoli, 2006). The thermal variation in single day in the city of Porto Alegre – RS, for example, can be rather high, generating a temperature gradient of up to 50°C on the surface of the facade. In an investigation looking to evaluate the durability of ceramic lining systems, carried out with ceramics and mortars adhered in concrete substrates through the induction of tensions of a thermal nature (Chew, 1992), determined a 20% reduction in the resistance of traction adherence of the ceramics when compared with systems that did not go through the action of the cycles.

Another significant degradation agent of the facades is humidity, which is characterized by the existence of water in the materials in a liquid, solid, or gas form (Ribeiro, 2006). The hygroscopic movement is a significant cause for the detachment of ceramic tiles (Bauer, 1995; Ribeiro, 2006). In order to limit the hygroscopic movements in ceramic facade linings, it is recommended to use low water absorption ceramic tiles (Goldberg, 1998). With this in mind, the British standard BS 5385-2 (BSI, 2015) specifies, both for extruded and pressed ceramic tiles, the use of tiles for facades with a water absorption below 3%. In this respect, the Brazilian standard NBR 13.818 (ABNT, 1997) does not provide a specific limit. In tests carried out on ceramic tiles in three different humidity conditions: air dried, with 0.2% humidity; slowly brushed with water, resulting in a 2.0% humidity; and submerged in water for a period of 30 seconds, with the tiles being kept in a vertical position before settlement in order to drain excess water, resulting in 8.5% humidity. It was verified that the greatest adherence between the ceramic tile and the mortar occurred with dried pieces and there was a decrease in adherence as the quantity of humidity of the tile increased at the time of its adherence (Bauer, 1995).

The durability of a facade lining system with ceramic tiles, therefore, depends on the exposure conditions. The contraction and expansion movements that result from the variance in temperature and humidity generate tensions in the bond with the substrate, which with the passage of time will result in detachments. These detachments of ceramic facade linings could occur due to adhesive rupture in the ceramic tile/mortar, mortar/gypsum, gypsum/thick frieze, and thick frieze/substrate bonds, or due to a cohesive rupture in the interior of any of these layers (Mansur, 2007). Regarding the rise of pathological problems in linings with ceramic tiles, it was observed that in 84% of the analyzed buildings there was detachment with adhesive rupture in the ceramic tile/frieze bond (Mansur, Do Nascemento and Mansur, 2012). This is due to the fact that this bond is the most requested area of the system for shear stress when thermal effects and the hygroscopic expansion of the ceramic tiles are considered (Abreu, Leitão and Lucas, 2004; Saraiva, Bauer and Bezerra, 2001).

Since the exposure conditions of a specific facade would be difficult to change, the useful life of the lining will depend on the decisions of the project and the quality of the execution, which will define the initial adherence resistance of the lining. The correct specification of the ceramic tile, adhesive mortar, and the adherence procedure is fundamental for this performance.

In this work, we evaluated the relation between the porosity of the ceramic tiles (using three types of ceramics with different water absorption), the composition of the mortar (utilizing two types of mortar), and the curing conditions (adopting the three different forms of curing stablished by the ABNT 14.081-4:2012 standard) with regard to the adherence resistance of the lining system.

2. MATERIAL UTILIZED

We evaluated compositions between a substrate-pattern, ceramic tiles with three different water absorption concentrations, two mortars, and three curing conditions. The substrate-pattern utilized for the adhesion tests was acquired through the provider standardized by the ABNT, addressing the requirements of the NBR 14.08-2 (ABNT, 2012). The absorption of the blocks is of 0.3 cm^3 of water in the course of 4 hours, being below the 0.5 cm^3 limit established by the standard.
Pressed ceramic tiles were utilized with three different water absorption levels (IIa, IIb, and III), which were determined through NBR 13.817 (ABNT, 1997). The water absorption was determined for each type of tile, in accordance to NBR 13.181 (ABNT, 1997), and the water absorption per capillarity in accordance to the specifications of the procedure of the RILEM TC 116 PCD (1999).
Table 1 shows the water absorption values of the ceramic tiles.

Table 1. Water absorption of the ceramic tiles

	BIIa	**BIIb**	**BIII**
Lower limit	3.01%	6.01%	10.01%
Result obtained in the test	4.80%	7.30%	12.50%
Upper limit	6.00%	10.00%	

All the ceramic tiles are within the limits stablished by the NBR 13.817 (ABNT, 1997), confirming the classification of the absorption group indicated by the manufacturer.
The water absorption profile (in g/cm^2) obtained by the procedure of the RILEM can be observed in Figure 1.
The average capillarity coefficient value of the type BIIa ceramic tile is of 0.046 $g/cm^2.min^{½}$, of the BIIb tile it is of 0.085 $g/cm^2.min^{½}$, and of the BIII tile it is of 0.185 $g/cm^2.min^{½}$. The ceramics of group BIIa have the lowest capillarity coefficient, followed by BIIb and, finally, the BIII tiles show the same behavior observed in the water absorption tests.

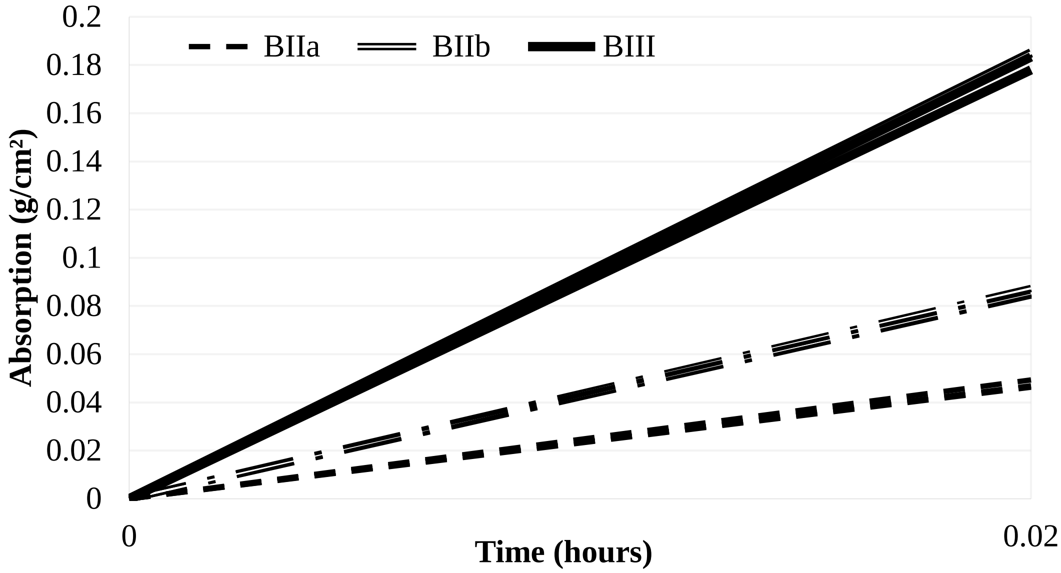

Figure 1. Water absorption per capillarity profile of the ceramic tiles

Two types of industrialized mortar for external applications were used: industrialized adhesive mortar type AC II and industrialized adhesive mortar type AC III, which possess in its composition more adherence promoting additives and water retainers than the type AC II.
The type AC II adhesive mortar used in the study is comprised of Portland cement CP IV (pozzolanic cement), sand, and additives. According to the manufacturer, the additive "Ecocel Uno" has the function of promoting little sliding, workability, and greater water retention. The "PLV 2000" product is a polymer that provides an increase in the chemical resistance and flexibility, in addition to better adhesion. The adhesive mortar type AC III, in addition to the cited materials, contains calcium formate. Calcium formate is a curing accelerator for Portland Cement based systems, promoting acceleration in the chemical reactions of the aluminates and facilitating the dissolution of the lime. It provides an increase of the open time, less permeability, and a significant increase of the mortar resistance.
The tests carried out in the experimental program are listed in Table 2.

Table 2. Tests carried out and their respective standards.

Characterization tests	Standard utilized
Tests in the fresh state	
Density of the apparent weight	NBR 14.086 (ABNT, 2004)
Consistency index	NBR 13.276 (ABNT, 2005)
Water retention	NBR 13.277 (ABNT, 2005)
Sliding determination	NBR 14.081-5 (ABNT, 2012)
Open time determination *	NBR 14.081-3 (ABNT, 2012)
Tests in the hardened state	
Absorption by capillarity	NBR 15.259 (ABNT, 2005)
Total water absorption	NBR 9.778 (ABNT, 2005)
Resistance to traction in the flexion	NBR 13.279 (ABNT, 2005)
Resistance to compression	NBR 13.279 (ABNT, 2005)
Determination of the dimensional variation and weight	NBR 15.261 (ABNT, 2005)

- Observation: for the execution of this test two sets were utilized comprised by the pattern substrate, ceramic tiles of the absorption group BIII, and adhesive mortar type AC II and AC III prepared in accordance to NBR 14.081-2 (ABNT, 2012) on the pattern substrate in the longitudinal direction.

Of the tests carried out for the characterization in the hardened state, only the test of resistance to traction adherence is planned for by a specific standard of mortars. The other tests were adapted from the standards of linings mortars. The results are shown in Table 3.

Table 3. Characterization of the mortars in a fresh and hardened state.

Mortar Characterization Tests:	**Results:**		**Limits specified by the Standards**
Fresh State	**AC II**	**AC III**	
Density of the apparent weight - γs (g/cm³)	1.46	1.44	-
Consistency index (mm) *	213	214	-
Water retention (%) *	99	99	-
Sliding determination (mm)	0.1	0.1	2
Hardened State	**AC II**	**AC III**	
Capillarity coefficient (g/dm².min½) *	3.49	4.96	-
Total water absorption (%) *	23.78	23.50	-
Vacuum index (%) *	34.51	35.69	-
Real specific weight (g/cm³) *	2.22	2.36	-
Resistance to traction in the flexion (MPa) *	2.5	2.6	Max abs. deviation ≤0.3MPa
Resistance to compression (MPa) *	3.9	4.3	Max abs. deviation ≤0.5MPa

* Adapted from the standards specific to lining mortars

In the fresh state, both adhesive mortar AC II as well as AC III obtained very close results, not being possible to distinguish them from the properties measured in those tests. In the Sliding Determination test the mortars showed the same value, which was lower than maximum 2 mm allowed by the NBR 14.081-5 (ABNT, 2012). In the determination of time in open sky, AC II had a result of 0.50 MPa and AC III of 0.62 MPa. The values obtained in the tests correspond to the NBR 14.081-3 (ABNT, 2012), which specifies a minimum value of 0.50 MPa. In the hardened state, the results for both mortars have very close values, except for capillarity, where mortar AC III obtained a higher value than that of AC II. The adhesive mortar type AC III has a dimensional variation greater than that of type AC II, with significant variation in the early ages, which can be observed in Figure 2.

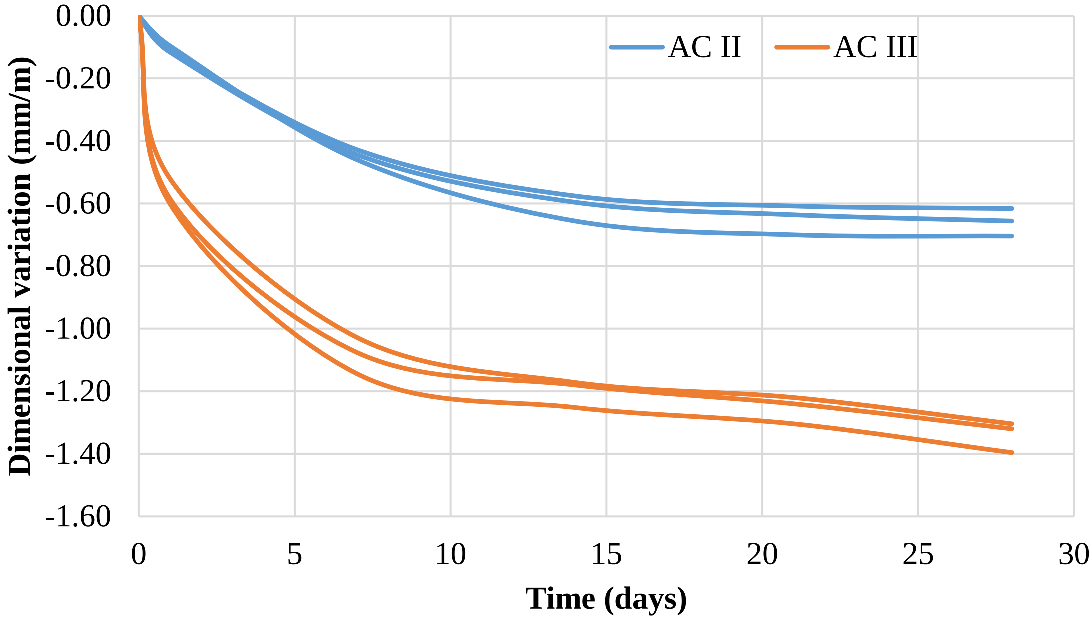

Figure 2. Dimensional variation of the mortars.

Both mortars show great weight variation in the first couple of days (with a variance of 5 to 8%), therefore, contrary to what was verified in the dimensional variation, the weight variation was greater for the type II adhesive mortars. Starting on the seventh day the variation of the two mortars began to stabilize, with little variance until the end of the test, in accordance to what is shown in Figure 3.

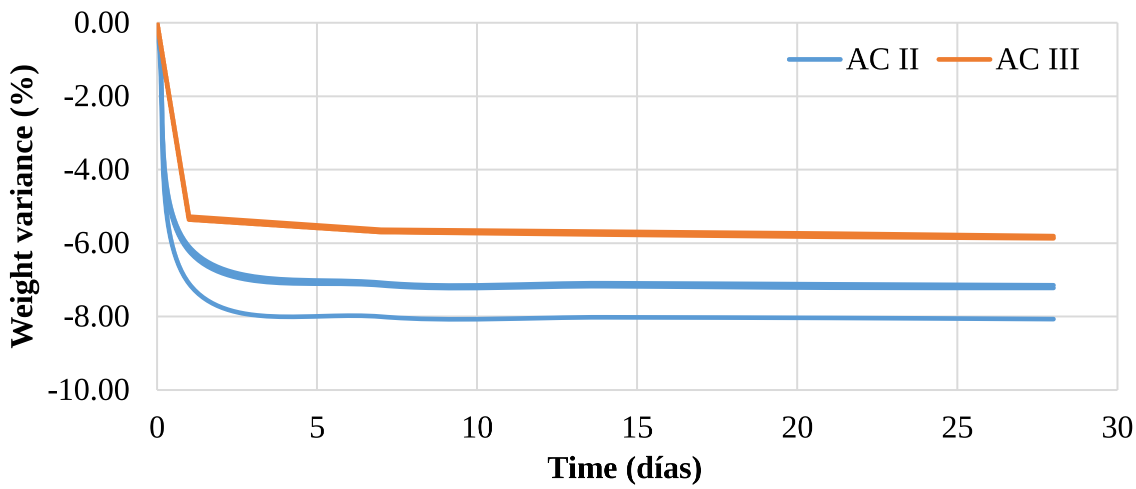

Figure 3. Weight variance of the adhesive mortars.

3. RESULTS AND DISCUSSION ON THE ADHERENCE OF THE SUBSTRATE-PATTERN/MORTAR/CERAMIC TILE SYSTEM

The various systems formed by the combinations between substrate pattern / mortar / ceramic tile were evaluated using the determination of the adherence resistance to traction and of the extension of the adherence. The compositions, in total eighteen sets of ten samples, were identified in the following manner:

- II and III: Type II and III mortars, respectively;
- BIIa, BIIb, and BIII: Ceramic water absorption group;
- N, IA, and AE: Types of curing to which the sets were subjected (normal, water immersion, and stove heating, respectively). The procedures seek to evaluate the behavior of the mortar in different curing situations: the normal condition simulates an ideal implementation condition; curing by immersion simulates the act of wetting due to rain and accumulations that can occur in tiles; and curing with a stove seeks to evaluate the effect of intense exposure to the sun during the curing period.

Following the setting of the ceramic tiles with the use of the mortar on the substrate-pattern, the sets were subjected to three curing conditions. In normal curing (N) the sets remained for 28 days in laboratory environmental conditions (a temperature of 23 ± 2ºC and a relative humidity of 60 ± 5%), in accordance to the specifications of the NBR 14.081-2 (ABNT, 2012). In curing with water immersion (IA) the sets were subjected to laboratory conditions for seven days, subsequently they were immersed in water at (23 ± 2) ºC, where they remained for twenty days. In curing with stove heating (AE) the sets were subjected to normal curing in a laboratory environment for 14 days, after which they were placed in a stove with forced ventilation at a temperature of (70 ± 2) ºC until the age of 28 days. The adherence resistance to traction test was carried out per the NBR 14.081-4 (ABNT, 2012), as can be observed in Figure 4. Ten tests were carried out in each substrate, evaluating the adherence resistance to traction and the extension of the adherence, following the curing period of the sets. The tests were carried out following the specifications of the NBR 14.081-4 (ABNT, 2012), using Dinatest brand equipment, model DS2-DPU-1100, with a maximum capacity of 5000N.

Figure 4. Metallic pieces attached on the ceramic tiles adhered to the substrate-pattern.

Figure 5 shows the average of the results obtained in the adherence resistance test carried out on the sets. Of the nine test sets of the type II adhesive mortar, only those subjected to normal curing complied with the minimum value of 0.5 MPa required by the NBR 14.081-1 (ABNT, 2012). Although the values of the adherence resistance to traction of the type III adhesive mortars were greater than those of the type II mortar, no set using the type III adhesive mortar achieved the minimum adherence value of 1.0 MPa required by the NBR 14.081-1 (ABNT, 2012).

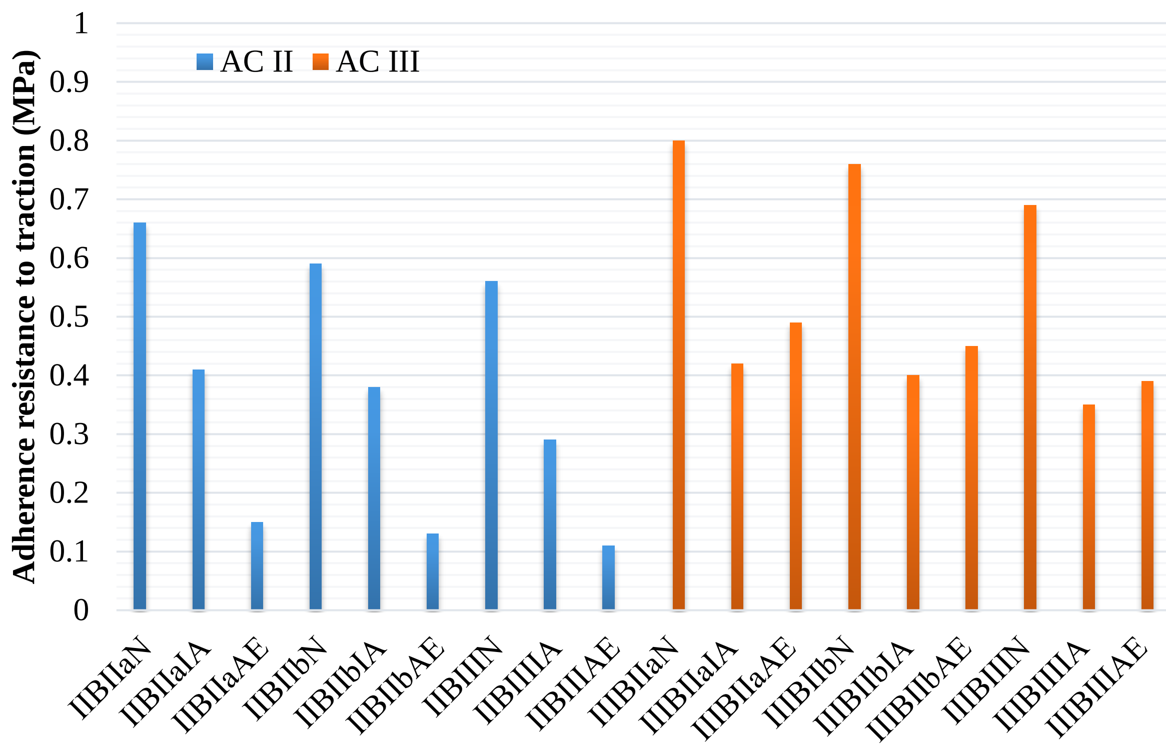

Figure 5. Results of the adherence resistance to traction of the sets executed and the minimum values to be reached, per the NBR 14.081-1 (ABNT, 2012).

The influence of the materials' properties in the adherence resistance of the sets was statistically evaluated. The significance of the effect of the studied variables (independent variables) in the adherence resistance was also evaluated. The results of the analysis are shown in Table 4.

Table 4. Variance analysis of the variables studied in relation to the adherence resistance.

	Sum of the squares	**Degrees of freedom**	**Sum of the average squares**	**Variance value**	**Level of significance**
Adhesive Mortar	1200.50	1	1200.50	22.5133	0.000476
Ceramic tile	245.78	2	122.89	2.3046	0.142235
Curing	5018.11	2	2509.06	47.0530	0.000002

Considering a 5% ($p < 0.05$) level of significance, it is verified that the type of curing is the variable that shows the greatest significant effect, followed by the type of mortar.
Comparing the characteristics of the mortars used, a hypothesis can be made regarding the behavior of the adherence resistance.
The greatest adherence resistance was obtained in the N curing processes (curing at a laboratory environment for 28 days). In the IA (water immersion) curing process, the adherence resistance fell to 60% for the type AC II adhesive mortar and 52% for the type AC III adhesive mortar. In this process, the curing occurs at laboratory temperature and humidity for seven days, followed by the immersion of the pieces. Considering that the two mortars used in the study are Portland pozzolanic cement based (with pozzolan doses of 50%), it can be estimated that the degree of hydration at seven days is still small and that the ensuing saturation, due to the immersion, results in a differential expansion of the ceramic

tile and/or the substrate; this causes shear stress in the interface with the mortar, reducing the adherence of the system. In the AE (with stove) curing process, the adherence fell to 22% for the type AC II adhesive mortar and to 59% for the type AC III adhesive mortar. A period of 14 days is used in this curing process followed by heating in a stove until the age of 28 days, which significantly harms the curing process of the pozzolanic cement and causes the lowest adherence resistance. For the type AC III adhesive mortar, losing the adherence resistance of the curing with water immersion is almost equivalent to losing the adherence resistance of the curing with stove heating, brought about by to the presence of calcium formate in its composition, which accelerates the increase of the adherence resistance at early ages.

It is observed that for all the mortars and curing conditions, the adherence resistance of the BIIa ceramic tiles was superior to that of the BIIb ceramic tiles, which was also superior to the adherence of the BIII ceramic tiles. This result has a direct relation with the water absorption of the ceramic tiles, indicating that excess water absorption can harm the adherence.

The internal face of the ceramic tiles used in the adherence test was photographed for the determination of the adherence extension. The program AutoCAD was used, implementing the "polyline" command and manually tracing the borders of the adhered region. Finishing the execution of the tracings, these were reticulated and the area was determined. Figure 6 (right) shows the reticule with the tracing highlighted in white and with the use of a transparency effect.

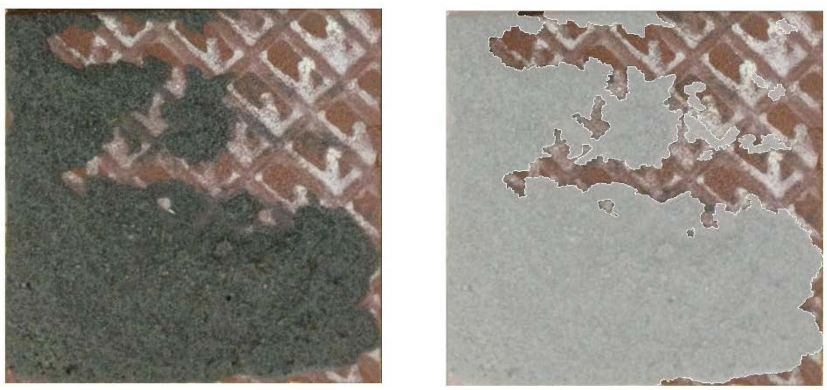

Figure 6. Visualization of the adherence extension of a ceramic tile.

Adherence extension was elevated in all the sets, as only the sets IIBIIbN and IIIBIIbN have an average adhesion extension value below 90%. Figure 7 shows the individual results for the adherence extension of the 180 tiles tested, making it possible to affirm that there is no direct relation between adherence extension and resistance. The adherence extension can be influenced by the nature of the materials that comprise the substrates and the mortars, as well as the properties of the mortars themselves (Maura, 2007). A good adherence extension, even when basic, is not enough to guarantee a good fastening of the mortar applied to substrates of ceramic blocks (Pagnussat, 2013).

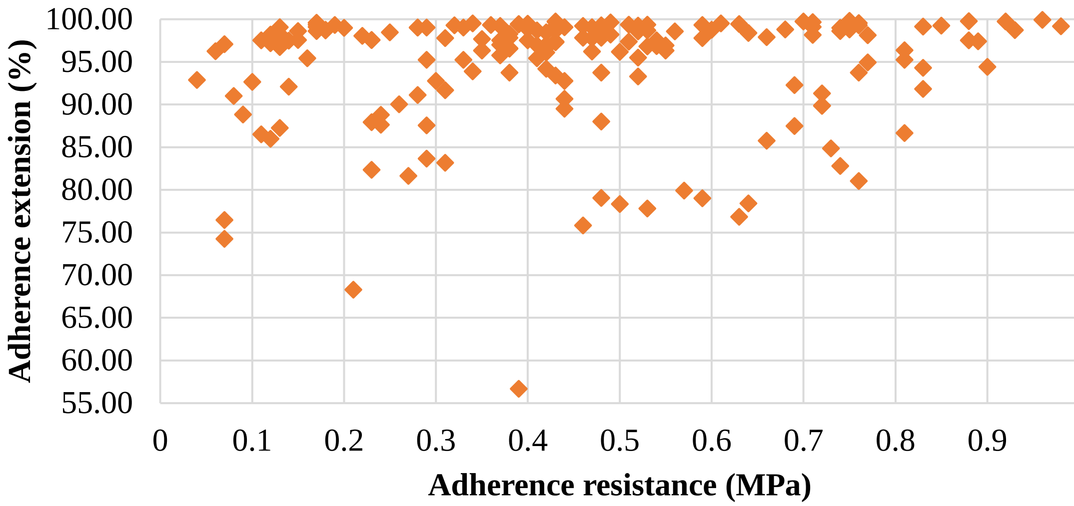

Figure 7. Adherence extension x adherence resistance.

The influence of the open time of the mortar (time between the mixing of the mortar with water and its usage) in the adherence resistance and extension of the ceramic tiles was evaluated for type AC II and AC III adhesive mortars and was shown to be significant. An open time of 5 and 20 minutes was used. The adherence resistance decreased close to 10% and the adherence extension decreased between 40 and 50%, as can be seen in Figure 8.

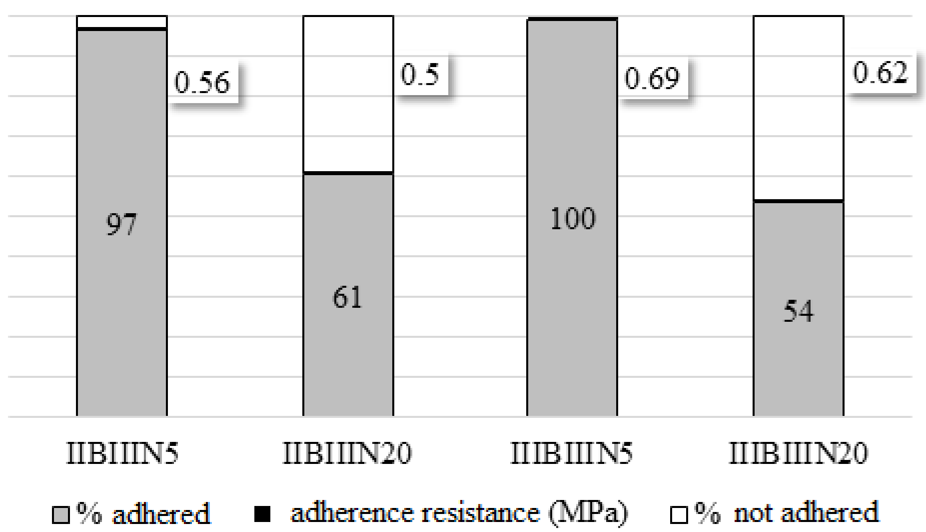

Figure 8. Adherence extension in terms of the open time of the mortars.

Figure 9 shows the adherence extension loss typical of the application of the ceramic tile after an excessive wait time, resulting in the loss of adherence extension and a decrease of the adherence resistance to traction. The phenomenon occurs due to the increase in the rigidness of the borders of the mortar, which hinders its distribution during the setting of the ceramic tile.

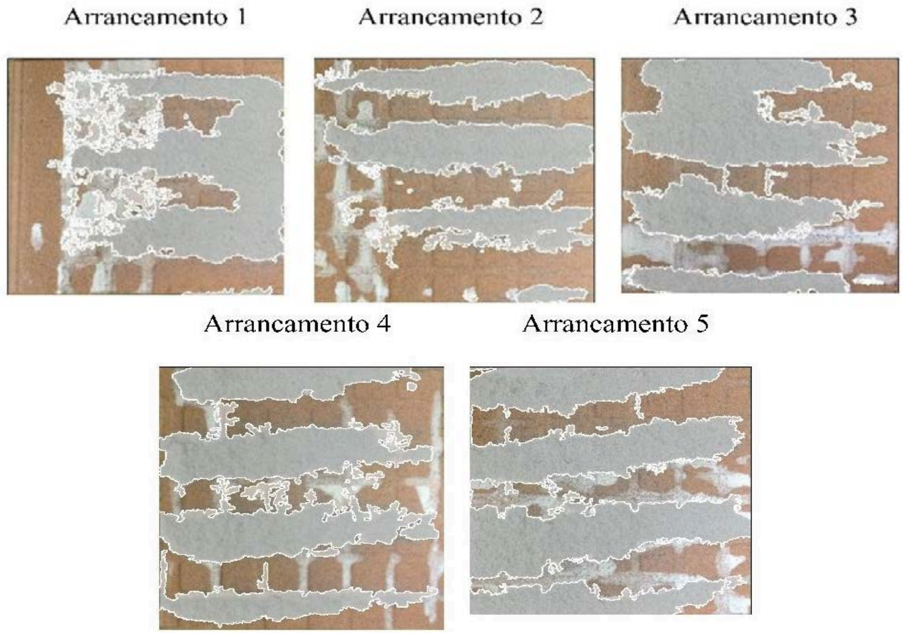

Figure 9. Adherence extension typical of the setting of the ceramic plate after an excessive wait time.

4. FINAL CONSIDERATIONS

Through the analysis of the results of the tests carried out, it can be observed that:

- For all the adhesive mortars used, all of which are Portland cement based, the curing condition is the most significant variable in the results for adherence resistance to traction, followed by the type of mortar. This highlights the curing differences typical of the application process of ceramic tiles in facades, where the pieces are subjected to significant differences in temperature and humidity, as well as the eventual wetting due to precipitation during the curing period. Normal curing (laboratory environment with a temperature of 23 ± 2ºC and relative humidity of 60 ± 5%) showed the best results, and it was the only curing condition in which the studied mortars were approved in the sets of tests provided for in the Standards;
- In a shared analysis of all the results, the characteristics of the ceramic tile, in terms of permeability, did not influence significantly in the adherence resistance of the system. Whereas considering a determined type of adhesive mortar and a specific curing condition, the increase in the water absorption of the ceramic tile implies a decrease in the adherence resistance;
- There is no statistically significant relation between the adherence extension and the adherence resistance of the ceramic tiles;
- The wait time between the mixture of the mortar with water and its use exercises great influence in the adherence extension of the ceramic tile and decreases its adherence resistance. This fact warns of the need for the specification of maximum times for the application of mortars, which ought to be controlled during the application;
- Considering the materials used, the only groups that reached the minimum adherence resistance to traction stipulated by the NBR 14.0891-1 (ABNT, 2012) were IIBIIaN, IIBIIbN, and IIBIIIN, all of which used the same adhesive mortar (AC II) and were subjected to the same type of curing (Normal).

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