Mechanical behavior of the system used in ventilated façade

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Gisela Colombo de Freitas[1,2]
https://orcid.org/0000-0001-8865-8429
Angela Waterkemper[1,3]
https://orcid.org/0000-0001-9045-5129
Aline Ribeiro[1,4]
https://orcid.org/0000-0002-3801-0250
Sara Medeiros dos Santos Pizzatto[1,5]
https://orcid.org/0000-0002-0648-4857
Oscar Rubem Klegues Montedo[1,6]
https://orcid.org/0000-0002-3350-6732
Elídio Angioletto[1,7]
https://orcid.org/0000-0003-4417-3440

[1]Universidade do Extremo Sul Catarinense – UNESC, Programa de Pós-Graduação em Ciência e Engenharia de Materiais – PPGCEM, Criciúma – Santa Catarina – Brasil.

E-mails : [2]gicacolombo@hotmail.com, [3]angela.waterkemper@eliane.com, [4]aline.ribeiro@eliane.com, [5]saramsp@unesc.net, [6]okm@unesc.net, oscar.rkm@gmail.com, [7]ean@unesc.net

Abstract

One of the solutions in civil construction to increase the life cycle of buildings is the ventilated facade due to its technical characteristics. Large porcelain tiles are used as a coating in this system, raising questions about its performance. This study used real size porcelain tiles (590 mm x 1190 mm) for pressure tests to evaluate the deformation suffered by the material at different pressure points, according to NBR 10821. In addition, the strength of the glass fiber-reinforced ceramic tiles has been tested against the impacts of rigid and soft bodies in a hidden clamp ventilated system, according to NBR 15575. Due to the wind, the system presented maximum deformation of 1.7 ±0.4 mm. When subjected to impacts, the system functioned within the norm for hard body strikes (20 J), meeting the requirements against minor proportions and wind pressures of up to 1480 Pa. Unsatisfactory performance when impacted by a soft body was observed. Such results show that the system needs to improve regarding resistance to major impacts.

Keywords: ventilated façade system. porcelain tile. performance standard. mechanical performance. hidden clamp system.

1. Introduction

A ventilated facade is a set that allows an efficient energy strategy for climates with hot summers and mild winters (Gagliano & Aneli, 2016; Stazi *et al.*, 2020; Maciel & Carvalho, 2019). It essentially consists of two opaque layers and a cavity (or cavities) vented between the two layers. There are several benefits for this system, for instance: energy efficiency, ease of maintenance and inspection, lower risk of detachment, resistance to degradation, creative potential, and thermal comfort in buildings, which makes it a competitive system (Ghaffarianhoseini, 2016; Zhou, 2010).

The increase in energy efficiency comes from the characteristic that in the outer layer, that is, in the coating, direct incident solar radiation is absorbed, and it is dissipated by natural convection in the ventilated cavity (Gagliano & Aneli, 2016). In addition, the inner layer of the facade acts as a building insulator from the thermal flux. The convection phenomenon also appears in the ventilated cavity and pushes warm air out of the facade, allowing cooler air to enter the interior (Martinez *et al.*, 2015). These buoyancy forces occur due to differences between indoor and outdoor air densities resulting from different temperatures and humidity levels. In addition, wind forces can help to remove hot air from the facade (Gagliano & Aneli, 2016).

Most studies related to ventilated facades are concerned with issues regarding energy efficiency and thermal performance. As an example, we can mention the effect of porous ceramic coatings applied on ventilated facades, which was used to evaluate the thermal behavior in an experimental apparatus (Pizzatto *et al.*, 2021). Porous specimens containing 40% by weight of lime mud and a firing temperature of 1100 ºC were evaluated in comparison with a commercial porcelain tile. The results showed that the ventilated facade composed of porous ceramic coatings developed in the study produced a greater reduction in temperature between the external environment and the interior of a representative box of a building, improving thermal comfort, and thus, reducing energy expenditure.

The ventilated facade also provides insulation and moisture control, preventing the presence of moisture and condensation (Gagliano & Aneli, 2016). The cladding of this system can be made of ceramic material, natural stone plates, metal, among others, and is separated from the building body by means of metal profiles.

To guarantee an adequate mechanical and thermal performance of buildings with the application of ventilated facades, choosing the materials appropriately in the design phase is primordial. Climatic conditions directly influence the need for different materials applied in different regions. In Europe, porcelain tile in ventilated facades is widely used. However, in literature, there are several studies with alternative materials for application in this type of system, such as porous ceramic slabs, glass, aluminum and jute fiber as reinforcement (Ahmed, 2016; Ribeiro *et al.*, 2019). For instance, porous ceramic slabs were used using two by-products, basalt and lime mud, according to the circular economy concept. In conclusion to this study, the porous ceramic developed has potential for use in ventilated facades, as it makes the construction system lighter and cheaper, when compared to the porcelain tile used commercially in the market, in addition to presenting a potential for thermal tests (Pizzatto *et al.*, 2021). A porous ceramic slab was developed using glass residue and lime mud for application in ventilated facades. In the performance test regarding the thermal insulation of the plates, the porous plate developed in this study presented better thermal performance in relation to the commercial porcelain tile using as a reference (Cammelli, 2016). Jute fiber was evaluated as reinforcement in the ventilated façade system of porcelain tiles. In this study, the evaluation was the behavior of the system in exposure to fire. Due to the nature of the fiber, it was consumed by the flames during exposure, requiring the use of flame retardants in the polymeric matrix (Ribeiro *et al.*, 2019).

The use of ventilated facades for different types of buildings, climates and design configurations has increased considerably in recent years (Maciel & Carvalho, 2019). In Brazil, some works already use this method, which aims to improve the habitability aspects of the building. This system can be designed for the renovation of existing buildings – retrofitting of facades (Martinez *et al.*, 2015) in the absence of norms related to historic-architectural preservation, as well as for its integration in the study of new buildings. In the Brazilian literature, detailed studies or essays on important properties of fixation systems are not found, such as the union between the fixators and the ceramic material and the mechanical resistance of ceramic materials with holes or cuts. There are no regulations specifically dealing with ventilated facades system (VFS). However, there is NBR 10821 (ABNT, 2017), which is attentive to the definition of the maximum displacement of the secondary structure (profiles), and NBR 15575 (ABNT, 2013), which, if adapted, is used for mechanical tests. There are no Brazilian standards or manuals that specify criteria for closure components (Cammelli, 2016).

Faced with this problem, for the first time, this study aims to evaluate the mechanical behavior of fastening systems used in VFS in circumstances such as variations in wind, pressure and impacts that may occur in the building.

2. Material and method

2.1 Materials

The glazed porcelain tiles were supplied by Elian Revestimentos Cerâmicos Ltda, in the format of 590 mm x 1182 mm with a thickness of 12 mm. The technical characteristics of this product are: flexural strength of 40 N/mm², breaking load of 2600 N, expansion was used by humidity of 0.2 mm/m and 0.4% of water absorption. Notches were made with a 1.5 mm thick Starfer precision cutting disc for porcelain tiles, to fit the VFS clamps. Fiberglass was attached to the back of the ceramic tile. This glass fiber was applied to the ceramic tile using a bicomponent epoxy resin. The fiberglass and epoxy resin used by Eliane Revestimentos Cerâmicos Ltda are supplied by Texiglass (Brazil) and Nanopoxy (Brazil).

For the assembly of the hidden clamp type VFS, the components used were: bushings and anchors (10 mm), aluminum anchoring brackets (40 mm x 80 mm x 1/2 mm), aluminum T profile (100 mm x 50 mm, 2.5 mm-thickness and 3000 mm-length), hidden clamp set, hexagon screw (body diameter of 7 mm, head diameter of 18.6 mm and 97 mm-length), nut (304), washer (304) and hexagon self-tapping screw (14 mm x 14 mm x25 mm and 6.3 mm-diameter). For fixing the ceramic pieces in the uprights, Ms Ultra Express Fischer were used. Sealing Glue, polymer based, stable consistency, maximum working time of 8 min, curing rate ≥ 3.0 mm after 24 h and ≥ 4.5 mm was used after 48 h, with a density of 1.48 ± 0.05 g/cm³.

2.2 Methods

2.2.1 Specimens

A set of VFS was built in the test chamber for the measurement of positive and negative pressures. A concrete block wall (140 mm x 190 mm x 390 mm) was erected in the dimension of 2590 mm x 2610 mm (h x l), supported on the mobile structure composed of metal beams and castors, as shown in Figure 1a. As shown in Figure 1b, this wall has transposition spaces that allow access to the amounts. These are intended for the installation of dial indicators used to measure eventual deformation at VFS (ABNT, 2017).

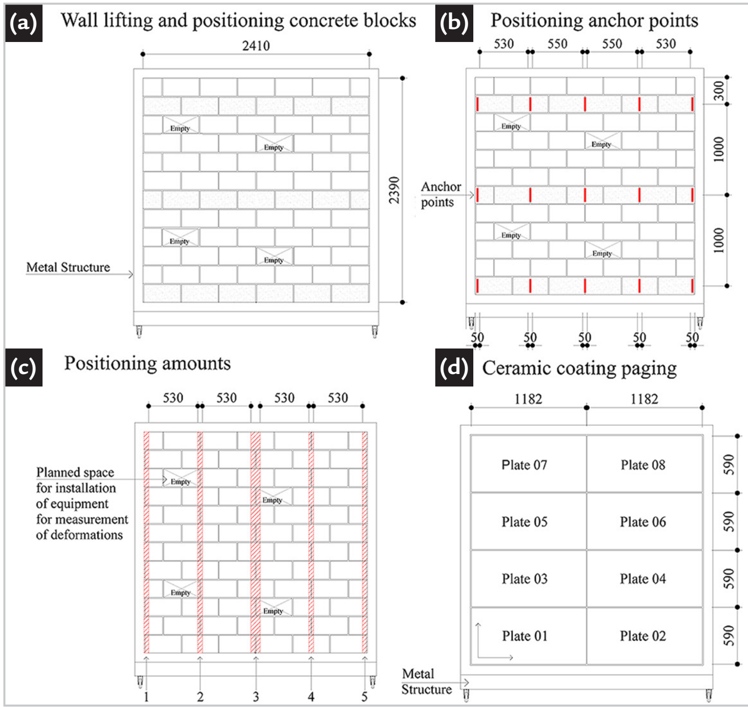

Figure 1 - Assembly of the specimens.

After the elevation of the wall, the VFS was installed according to the assembly project shown in Figure 1c. In profiles 1, 3 and 5 the hidden clamp type fittings were fixed, in addition to a layer of sealant glue to stabilize the ceramic piece. Profiles 2 and 4 serve as support for the system, receiving only the sealant glue layer. The VFS was assembled according to the layout shown in Figure 1d.

2.2.2 Uniformly distributed load tests

For the test of uniformly distributed loads, a test chamber was used to measure for positive and negative pressure according to standard (ABNT, 2017). The chamber used has the dimensions 2600 mm x 2600 mm x 600 mm (h x l x w). The specimen must be positioned in the test chamber with the coated side facing the inside of the chamber, therefore, the uniformly distributed wind loads, whether pressure or suction, are exerted on the front face of the specimen. Four magnetic supports (model 7010SN - Mitutoyo brand) and four dial indicators (model 2046S - Mitutoyo brand) were used to measure the deformation from occasioned pressure and suction tests. Figure 2 shows the system fitted to the test chamber and the dial indicators installed and identified by numbers 1, 2, 3 and 4.

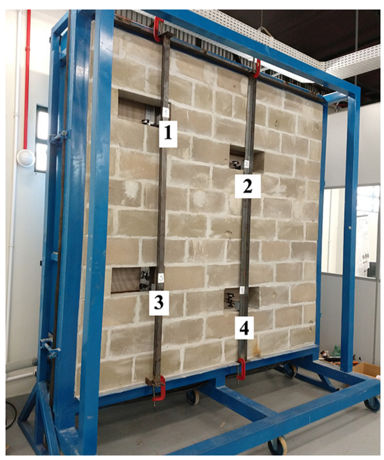

Figure 2 - Location of pressure test equipment.

For the tests of uniformly distributed loads - pressure and suction - the data from the standard (ABNT, 2017), adapted for ventilated facades, were used. The positive pressure (pressure) and negative pressure (suction) values were performed using an Impac 2 PSI digital micromanometer. For each test pressure (Pe) 4 points were analyzed, where each test was repeated 3 times for greater precision of the results.

For pressure tests, after checking the values determined for the study of wind pressure according to Table 1, the chamber was subjected to pressures according to the region where the tests were carried out, in the city of Criciúma - SC, which is in the region Country IV (ABNT, 2017). For the suction tests (negative pressure), the maximum measurements obtained in the test chamber were used, due to equipment limitation. Thus, the tests were performed with values lower than those tabulated in the standard for region IV, with values ranging from -460 to -950 Pa.

2.2.3 Soft body tests

The soft body and hard body impact tests were performed according to the performance standard NBR-15575 (ABNT, 2013). This requirement of the performance standard consists of the resistance of vertical sealing systems to the impact energy of accidental shocks generated by the building's own use or shocks caused by intentional or unintended intrusion attempts.

Table 1 - Wind pressure values according to region IV.

Number of Floors	Maximum height	Country Region	Positive test pressure - Pe (Pa)	Positive safety pressure -Ps (Pa)
2	6 m	IV	770	1160
5	15 m	IV	950	1430
10	30 m	IV	1130	1700
20	60 m	IV	1350	2020
30	90 m	IV	1480	2210

NBR 15575-4/2013 (adapted).

The soft body impact tests are applied by means of an impactor released in a pendulum movement of different heights, always reaching the opaque parts of the facades, that is, outside the regions of the frames, in the most unfavorable sections of the component or construction element. The impacts are applied by a cylindrical leather bag, with a diameter of 350 mm, height of 700 mm and a mass of 400 ± 4 N.

The impact values for the facade tests are defined based on the identification of the type of facade to be tested (ABNT, 2013). The test pieces used fit the vertical sealing element without structural function and the values ranging between 120 and 720 J.

The standard (ABNT, 2013) recommends that the tests of impacts with hard bodies be applied by steel balls with a diameter of 50 mm/5 N mass (impacts of use) and a diameter of 62.5 mm / mass of 10 N (safety impacts), that is 0.5 kg and 1.0 kg respectively. The impact values for the facade tests are defined based on the identification of the type of facade to be subjected to the test and the specimen fits into the vertical sealing element with or without structural function (ABNT, 2013). The tests are divided into use test and safety test, where the impact energy of 3.75 J refers to the use and 20 J to the safety test.

3. Results and discussion

3.1 Tests of uniformly distributed loads

Figure 3 presents the individual analysis of the pressure points (point 1, point 2, point 3 and point 4). It is possible to observe that the greater the positive pressure (Pa), the greater the deformation (mm) suffered by the ceramic plates of the system.

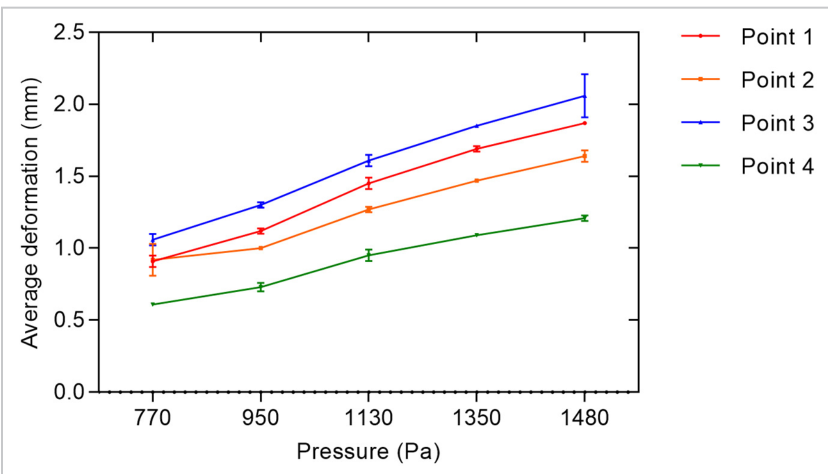

Figure 3 - Graphs of the deformation (mm) suffered at points 1, 2, 3 and 4 according to the pressure (Pa) exerted on the system.

The graphs show that points 1 and 3 showed a linear increase in deformation, while points 2 and 4, mainly, presented lower values of deformation with increasing pressure. As the system guarantees a uniform pressure, the difference between the measurements is in the characteristics of the materials and the assemblies performed. Thus, differences between the measured points are expected, but should not be very significant.

The graph in Figure 4 reinforces the strain (mm) x pressure (Pa) analysis obtained at each point, taking into account the average between them. Individually, it can be seen that with the gradual increase of the pressures (Pa) exerted, the deformation (mm) suffered by the ceramic plates of the system increases linearly.

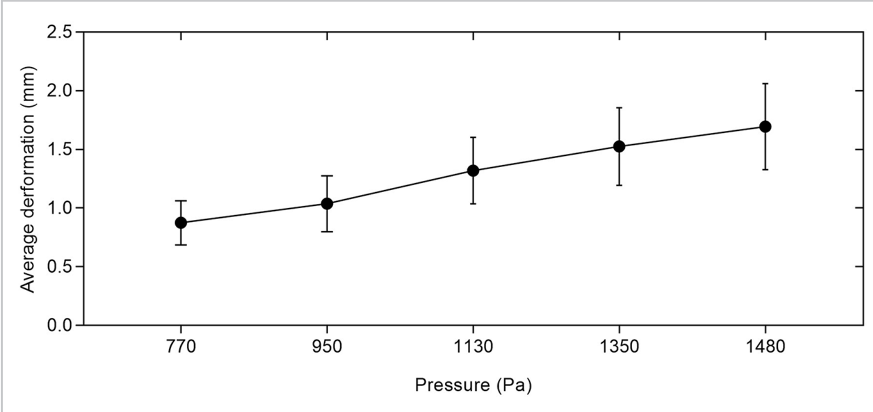

Figure 4 - Graph of the mean deformation suffered at the 4 points according to the 5 values of positive pressure (Pa) exerted on the system.

Figure 5 presents a graph showing the relationship between pressure negative (Pa) and whit deformation (mm) exerted on the system, where: a) it corresponds to the deformation suffered by point 1, b) point 2, c) point 3 and d) point 4. In the individual analysis of the points for the 5 pressures exerted, there is a variation in the linearity of the deformations obtained in the pressure / suction (Pa) x deformation (mm) ratio.

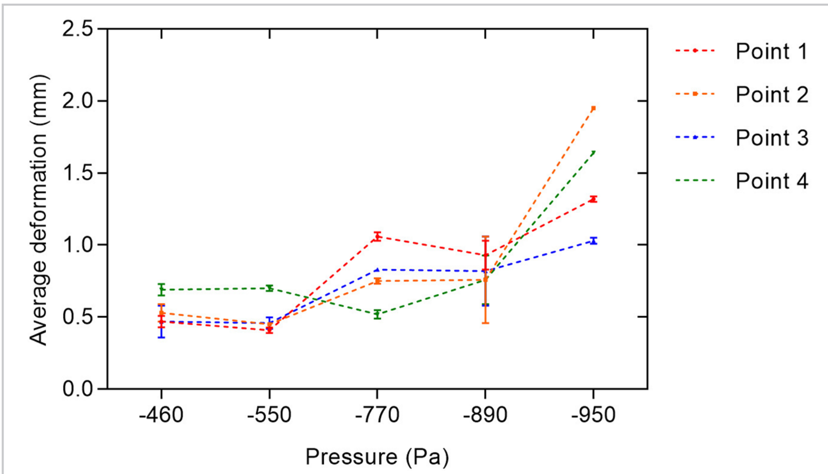

Figure 5 - Graphs of the deformation (mm) suffered at points 1, 2, 3 and 4 according to the negative pressure (Pa) exerted on the system.

It was noted that there was no linear increase in the deformation of the points as the suction of the system was more intense, that is, the pressure was more negative. It was noticed, mainly, an oscillation in the average deformation in the negative pressures of -550 and -890 Pa.

The graph in Figure 6 shows the values of strain (mm) x pressure (Pa) through the analyzes obtained individually at each point, as an oscillation in the deformations is perceived, there is no linear increase in strain (mm) x pressure (Pa) suffered by the ceramic plates of the system, where each point on the graph is the average of the 4 points at the same pressure.

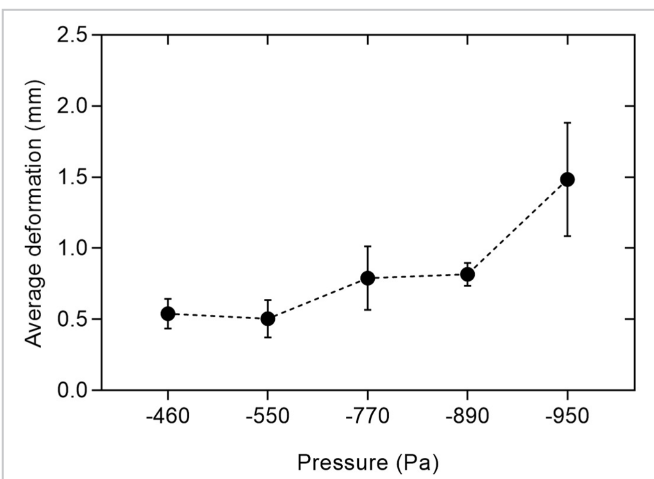

Figure 6 - Graph of the deformation suffered at the 4 points according to the 5 negative pressure values (Pa) exerted on the system.

3.2 Impact tests

The soft-body impact tests on plate 1 are shown in Figure 7. The occurrence of cracks in the energy impact of 120 J, depletion in the energy impact of 180 J and rupture in the energy test of 240 J were noticed. The other energies foreseen in the norm - 360, 480 and 720 J - were not performed, as the specimen broke in the third stroke. The rupture of the glass fiber adhered to the plate was also observed.

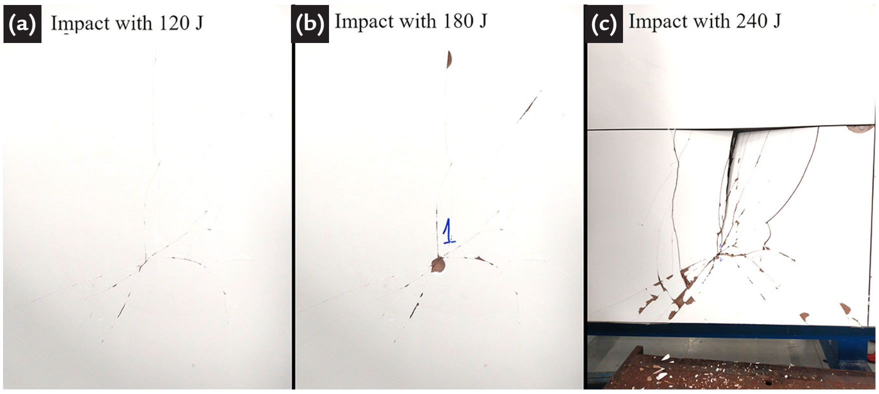

Figure 7 - Visualization of the soft body impact test.

In none of the specimens did large chipping occur. The dimensions of the largest chips that came out of the plates after the impact of the two tests ranged from 30 to 65 mm.

It was noted that there was a fracture of the ceramic at the locations of the hidden clamp system in the two tested plates, even when the impacts occurred in distant locations. In plate 1, the rupture occurred with the impact of 180 J of energy, while in the plate 4, it occurred with an impact of 240 J. Figure 8 shows the fracture in plates 1 and 4.

Figure 8 - Attachment of the hidden clamp system after impacts on the plates 1 and 4.

After the tests, the plates showed cracks and sinking, thus noting a failure of the system. The performance levels achieved in these tests were minimal (M), while the standard requires intermediate levels (I) - no failure occurrence - for the energy impacts of 120, 180 and 240 J. For the hard body tests, plates 2 and 4 were tested. Plate 4 received impacts with a 0.5 kg steel ball while the plate 2 received an impact with a 1.0 kg ball. For the steel sphere of 0.5 kg and 3.75 J of energy (small size) the plates resisted to eight impacts without occurrence, a slight sinking and a rupture being classified with minimum performance level.

For the large proportion hardbody test, plate 2 was tested. Figure 9a shows the ventilated facade ceramic plate after the 10 impacts of the 1.0 kg hard body and 20 J energy and Figure 9b shows the glass fiber adhered to the plate after the impacts. It can be seen that there was no fiber rupture after the impacts, even with the occurrence of cracking in the ceramic plate.

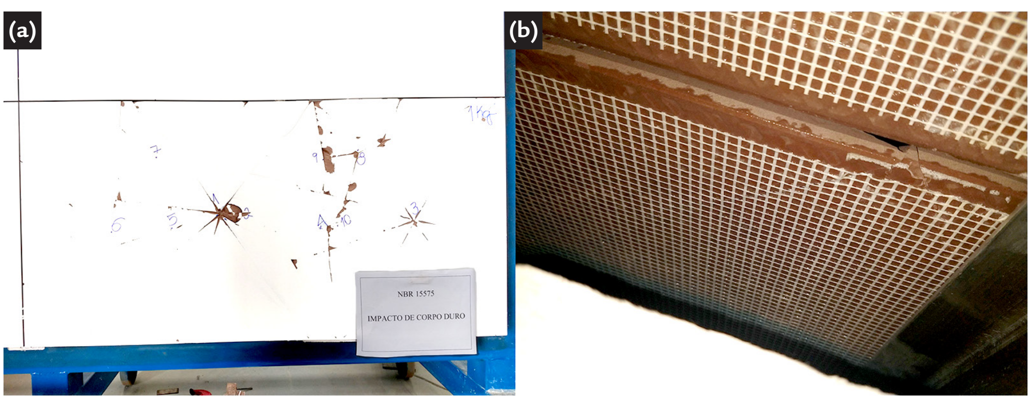

Figure 9 - (a) Ventilated plates facade and (b) glass fiber adhered to plate after impacts of 1.0 kg and 20 J hard bodies.

The tests with large hard bodies - 1.0 kg steel ball and 20 J of energy - after 10 blows showed 3 occurrences of cracks without detachment; 4 with light cracks; 2 sinking; 1 crack with medium detachment; For impacts of 3.75 J (use impact), little damage was recorded, but cracks and sinking occurred, even if minimal. In the safety test, 20 J, the system showed cracks, cracks and sinking, but without sphere crossing or system failure. Thus, the system presented the minimum performance for impacts, provided for in the standard.

4. Conclusions

In this study, it was observed that in the pressure chamber tests, the results obtained with positive pressure showed that the greater the incidence of winds on the facade, the greater the deformation suffered by the ceramic tile.

In the suction tests (negative pressure), with the pressures used in the laboratory, it was not possible to observe the linearity in the deformation. Possibly this fact is due to factors not directly linked to the VFS (air leaks, or insufficient suction power). Regarding the resistance of the system to pressure, it was understood that the results of the tests were acceptable, with values of deformation varying between 0.5 and 2.0 mm. The system did not present displacements, detachments, cracks or breaks when subjected to pressures foreseen in the norm.

For soft body impact tests, the system's performance was considered insufficient as it did not meet the strength requirements of the standard. The specimen must be hit with 6 energies of increasing values at each blow and resist without suffering ruptures. In this study, the ceramic plates broke on the 3rd blow, the same thing happens with the fiberglass adhered to the plates. Two soft body tests were performed for greater result accuracy, and in both tests, the plate ruptured on the third blow, subjected to an energy of 240 J.

In the hard body impact tests, the system presented the minimum performance foreseen in the norm. The specimen, when subjected to blows from steel balls with a mass of 0.5 kg (10 J), showed cracks and surface dents. When subjected to a 1.0 kg sphere (20 J), it showed sinking, cracks and detachment. Even so, it can be considered that its performance meets the minimum required by NBR 15575/2017, as there were no breaks or leaks in the ceramic tiles.

When analyzing the tests performed on the system as a whole, it can be seen that it has a behavior considered uniform because although there are differences between the measured points, they do not interfere in a way that harms the whole. Improvements must be conducted for the ceramic parts and also in the reinforcement material. The results show that the tested VFS has the resistance required as a standard for pressure and suction tests, and for hard body tests. As for the tests carried out with soft bodies, the results were insufficient, requiring a more in-depth study for the development of materials with the required resistance levels.

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