DEVELOPMENT OF A FIXING SYSTEM FOR VENTILATED FAÇADES WITH LOW-THICKNESS PORCELAIN TILE

Karina Felisbino Campos[(1)], Humberto Ramos Roman[(2)]

[(1)] MSc. Universidade Federal de Santa Catarina (UFSC), Brazil

[(2)] Prof. PhD. Universidade Federal de Santa Catarina (UFSC), Brazil.

ABSTRACT

Currently, there is a large growth in technological innovation, enabling the execution of projects with innovative building systems. The façade has a fundamental importance in the presentation of the building and there is a trend of covering façades with ceramic tiles, providing the building with greater protection. Specifications are focused on new materials and construction techniques in order to have a greater aesthetic value of the projects, to achieve productivity growth in the construction works, to increase the performance and to specify materials and services of quality. The technology of ventilated façades has several advantages such as: greater agility in the lead time of the construction work, more security regarding the fixing of the pieces, improved performance of the thermal comfort, and reduced problems of water infiltration when compared with the traditional system. The purpose of this paper is the dimensioning of a ventilated façade using low-thickness porcelain tile as cladding, and fixing the tile on an auxiliary aluminium substructure, this executive technique being used for glass curtain walls. The dimensioning is based on the determination of loads due to wind and the wind is the loading applied on the auxiliary aluminium substructure and low-thickness porcelain tile. For the structural behaviour of the auxiliary aluminium substructure, the values for maximum allowable deflection, minimum moment of inertia, minimum resistant moment, linear thermal expansion and active tension are calculated. For the low-thickness porcelain tile, the bending resistance is calculated and then the necessary quantity of supports to the structure is determined. The connection of the auxiliary aluminium substructure and low-thickness porcelain tile is made by means of a structural sealant. The dimensioning of the structural sealant is also verified by determination of tensile and shear strength for the façade which has been studied here. The building system of ventilated façade with low-thickness porcelain tile is described. The compatibility between the materials and dimensions according to specifications is verified.

1. INTRODUCTION

The ceramic industry has constantly improved the development of new products, making it necessary to seek alternative installation techniques. These installation techniques, associated with the ceramic tiles can result in significant improvements in system performance and offer new opportunities that result in quality in the buildings.

The tile manufacturers have been seeking the development of sustainable products and systems. The ventilated façades and the porcelain tiles of low thickness stand out in the construction market for their characteristics with regard to thermal comfort, energy savings and lightweight construction systems.

The façade is the first visual impression of a building. It is considered the visiting card of a building and it is also responsible for its protection and durability.

Ventilated façades increase the energy efficiency of buildings with characteristics of a sustainable system. The ventilated façade system consists of a space between the support base of the building and the ceramic tile, defined as an air chamber. The ceramic tiles are fixed to the frame by means of mechanical anchors. The improvement of thermal comfort is achieved by air circulation, since the variation in the air density inside the air chamber makes the heated air rise so that it is replaced with cooler air. This flow constantly occurs inside the air chamber, and is characterized as the chimney effect.

The method of execution of the ventilated façades can be used in new constructions and remodelling. The façade execution process is considered fast, since the ceramic tiles and mechanical anchors are pre-fabricated materials. Ventilated façades are characterized by a building system that promotes agility in execution, high productivity, reduction of steps to control the receipt of materials and production, easy maintenance, etc.

The standard porcelain tiles have thickness of around 10mm. In Europe, a technology for the manufacture of porcelain tiles with low thickness and large format was developed.

Low-thickness porcelain tiles are characterized by aesthetic and dimension versatility. It is recognized as the most innovative product and the most innovative technological process that the ceramic tile industries have developed in recent years.

Low-thickness porcelain tile is defined as an unglazed porcelain tile with water absorption of around 0.1%. Currently, in the Brazilian market, it has maximum commercial dimensions of 3x1m, and weight of 7kg/m². It is also possible to have thicknesses of 3.5mm, 7mm and 11mm and this is possible by joining pieces and inserting fiberglass on the back of the piece to provide mechanical strength and security for the handling and transport of the product. This paper focuses on pieces of 3x1m and 3.5mm of thickness (3mm porcelain tile and 0.5mm fiberglass), resulting in 8 kg/m².

As this product has low thickness and a large format, the installation technique for ventilated façades is very similar to that of glass curtain walls.

2. CONSTRUCTION SYSTEM OF VENTILATED FAÇADE WITH LOW-THICKNESS PORCELAIN TILE

First of all, for a ventilated façade execution method, the compatibility of the architectural design with the ventilated façade constructive system, the verification of the wind load according to the dimensions of the building, location and topography must be verified.

The definition of the auxiliary aluminium substructure is directly related to the dimensioning of the vertical profiles and horizontal profiles, bending resistance of low-thickness porcelain tile and structural sealant. An air chamber was provided in order to make the system work with ventilation. The components and accessories for the composition of the ventilated façade system were defined. The choice of profiles was carried out by the calculations for the structural behaviour and compatibility of the profiles used for the curtain walls on the Brazilian market.

The construction system of the ventilated façade has a total weight of 12kg/m². The low-thickness porcelain tile is considered a lightweight material, as it only weighs 8kg/m². The auxiliary aluminium substructure weighs 4kg/ m².

The use of vertical and horizontal profiles and anchorages was defined according to wind loads. These items have the structural function in the system. The so-called sheet profile was also defined, featuring a peripheral profile, which envelops all sides of the low-thickness porcelain tile. The sheet profile with the low-thickness porcelain tile and structural sealant make up a framework. The union of the sheet profile and low-thickness porcelain tile is performed by the structural sealant.

The façade studied is defined by Stick system. The installation of the Stick façade is made piece by piece. First, the vertical profiles are fixed, then the horizontal profiles and finally the sheet profiles (already bonded to the porcelain tiles of low thickness, as a framework – the term "framework" was adopted to explain the union of sheet profile+ porcelain tiles of low thickness + structural sealant). Figure 1 shows a drawing with the main profiles, components and accessories of the auxiliary aluminium substructure, while figure 2 shows the Stick System.

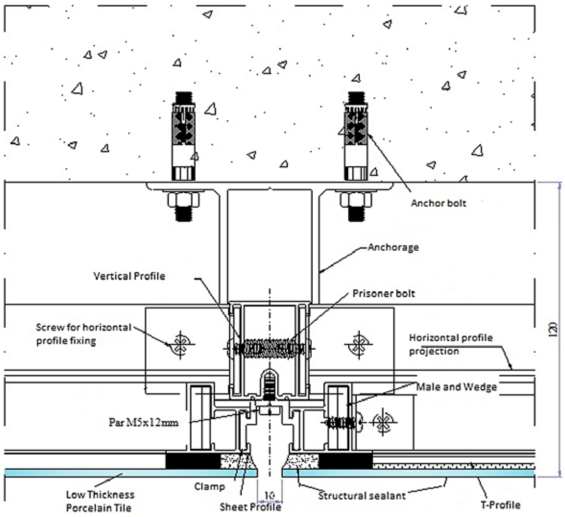

Figure 1 – Details of the System (mm).

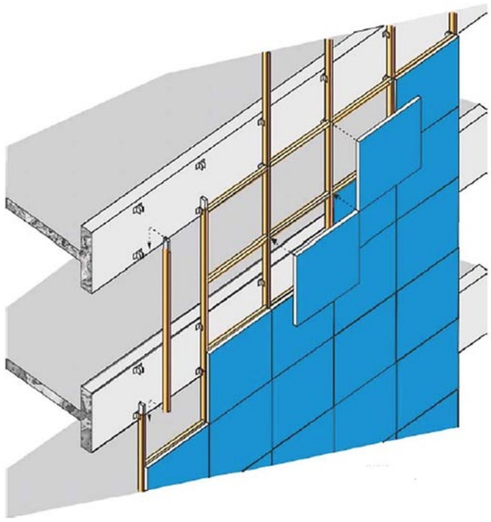

Figure 2 –Stick façade (Santos, 2005).

For the installation of a ventilated façade, the first step is the installation of anchorages, responsible for the connection of the façade construction system to the base support of the building.

Through expanding stainless steel anchor bolts, the anchorages are set in areas of concrete. The vertical profiles are fixed to the anchorages by a bolt. After installing the anchorages, the vertical profile is fixed by a screw called a prisoner bolt. After the installation of the vertical profiles is carried out, the horizontal profiles are fixed. The horizontal profiles are fixed to the vertical profiles through fasteners previously placed in the vertical profiles.

The anchorages have a structural function and determine the alignment of vertical and horizontal profiles and it is also responsible for bearing the loads of its own weight, the ceramic tile weight and the loading of the external environment.

The connection of the framework with the system is performed by clamps. The clamp is part of the sheet profile and makes up a pre-assembly of the clamps along the sheet profiles before being sent to the construction. A screw (M5x12mm, in a black colour) fixes the clamps to the vertical and horizontal profiles. A system of male and wedge is responsible for closing the sheet profile with a 45 ° angle.

The spacing between the low-thickness porcelain tiles (or joints) is 10mm. The dimension of at least 10mm is determined by the size of the screw (M5x12mm Par), because it is necessary to fix the screw between the joints to execute the fixing of the framework to the vertical and horizontal profiles.

With this type of construction system that uses clamp fastenings, it is possible to assemble and disassemble each frame individually. The screw is simply removed and the sheet profile (framework) is taken out. This advantage is very important because if there is any need to replace a low-thickness porcelain tile, this can be replaced easily without disturbing other pieces that make up the façade. All profiles are extruded and anodized in black.

The air chamber is determined by the installation of the building system and has a maximum thickness of 120mm. The minimum thickness is 70mm and is determined by the area required for installation of the auxiliary aluminium substructure. The air chamber is designed so as to work with the ventilation system. Thus, the upper and lower openings and also the 10mm joints remain open.

A perforated sheet of aluminium is used for the finish at the top and bottom of the air chamber. This sheet serves to close the chamber and prevent the presence of undesirable elements (such as insects, leaves, etc.).

An aluminium T-profile is used that is attached to the back of the low-thickness porcelain tile. This profile has to prevent bending stresses on the framework. The determination of the profile on the back of the low-thickness porcelain tile is performed by the structural sealant. The T-profile is also fastened to the sheet profiles by means of screws. The application of the T-profile was determined by calculation of the bending resistance at every 75cm.

The profile map is reported in figure 3. The dimensions, shapes and structural data of each profile are presented: vertical, horizontal, sheet, clamp, anchorage, T-profile (support), male and wedge connection. The moments of inertia (Jx and Jy), resistance moments (Wx and Wy) and distance from the centric (X and Y) are also detailed.

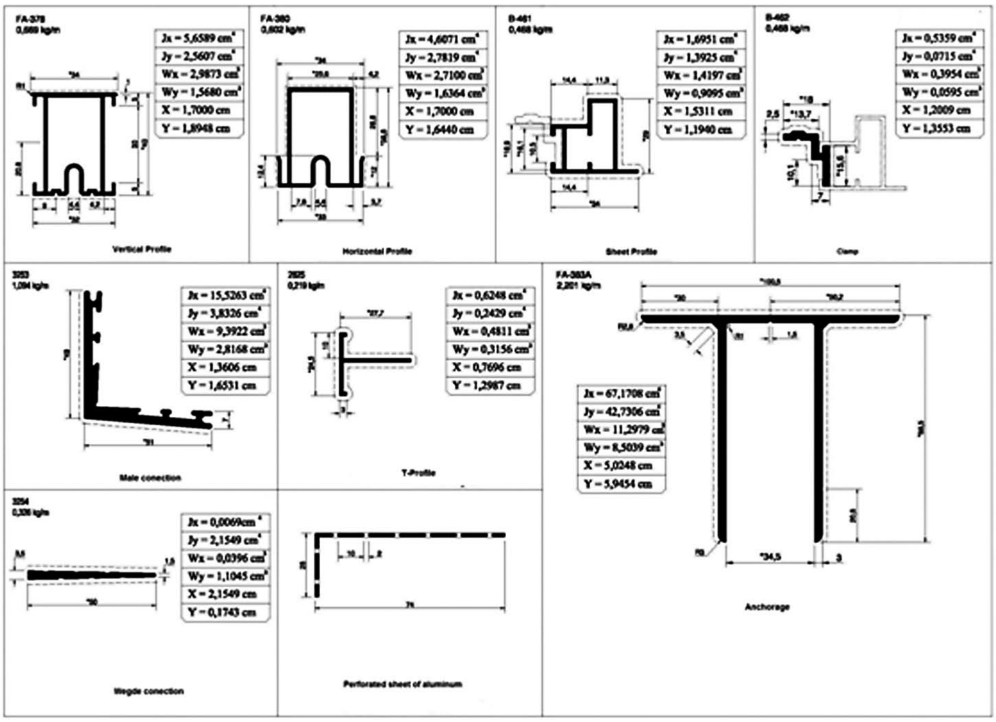

Figure 3 – Profile map of the auxiliary aluminium substructure.

It is very important to determine the structural behaviour of the profiles. For example, the vertical profile supports its own weight, ceramic tile weight and wind loading. The installation of the vertical and horizontal profiles defines the orthogonal plane in order to carry out the frameworks (sheet profile with the low-thickness porcelain tiles).

Figures 4 and 5 show the system made by the sheet profile, low-thickness porcelain tile and structural sealant. Clamp fixing is also shown. First of all, the sheet profile is closed like a board (with the sheet profile + low-thickness porcelain tile + structural sealant = framework). The second step consists of applying the spacer (polyethylene foam tape with adhesive sides) which serves to keep the low-thickness porcelain tile in the ideal position to receive the structural sealant. This is inserted into the remaining space between the sheet profile and the low-thickness porcelain tile. After the application of the structural sealant, it is necessary to wait for it to cure, and later to send this to the building for assembly in the vertical and horizontal profiles.

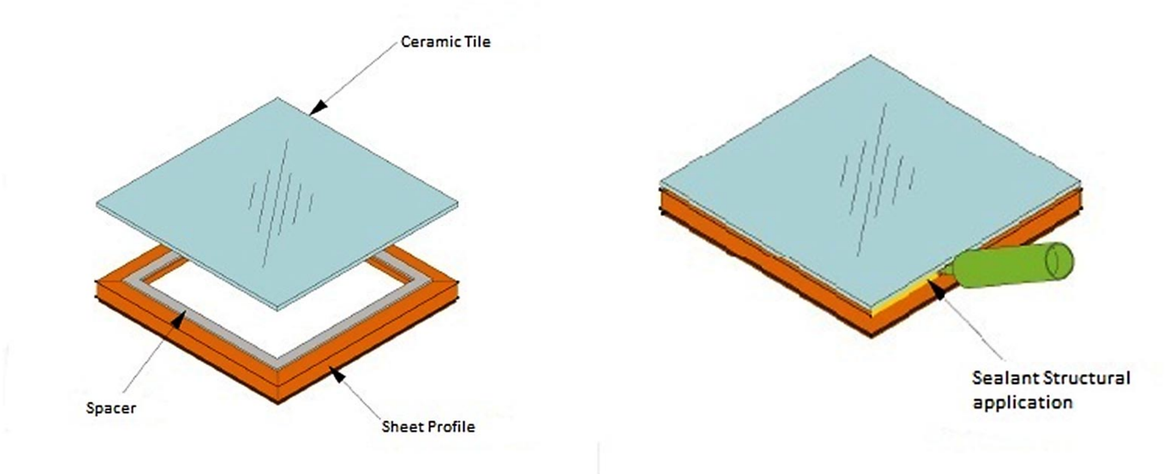

Figure 4 –Assembly of sheet profile + low-thickness porcelain tile + structural sealant = framework. (Tecnologia&Vidro, 2000).

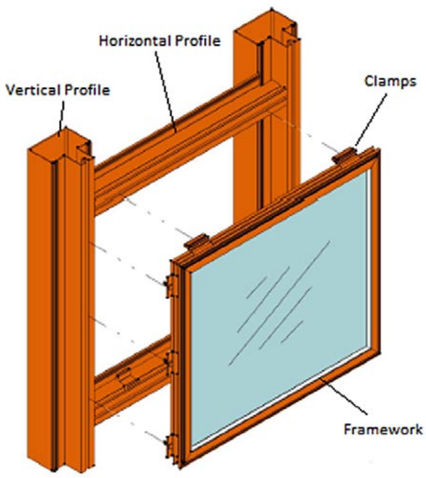

Figure 5 –Fixing System by clamps (Tecnologia&Vidro, 2000).

Figures 6 and 7 show the profiles, components and accessories for installation of the ventilated façade, such as the low-thickness porcelain tile, vertical profile, sheet profile, anchorage, anchor bolt, prisoner bolt, spacers, clamp and structural sealant.

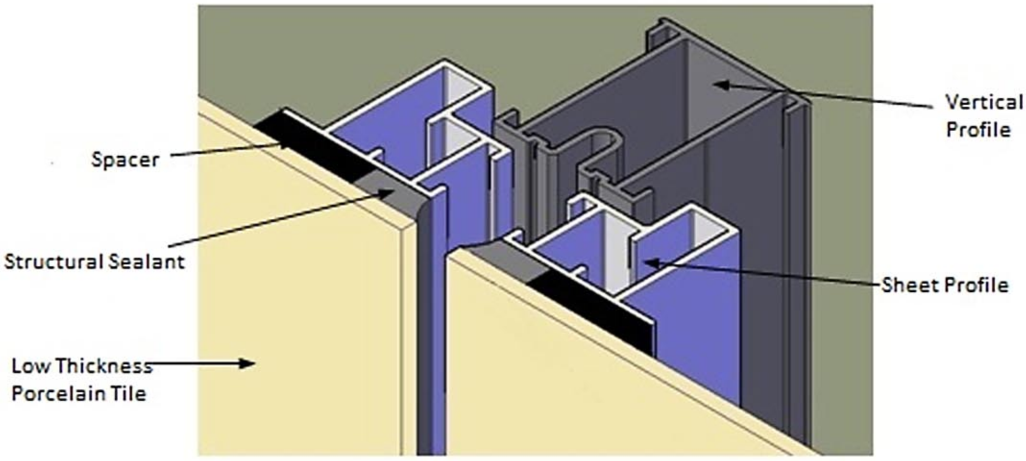

Figure 6 –Detail of the joints.

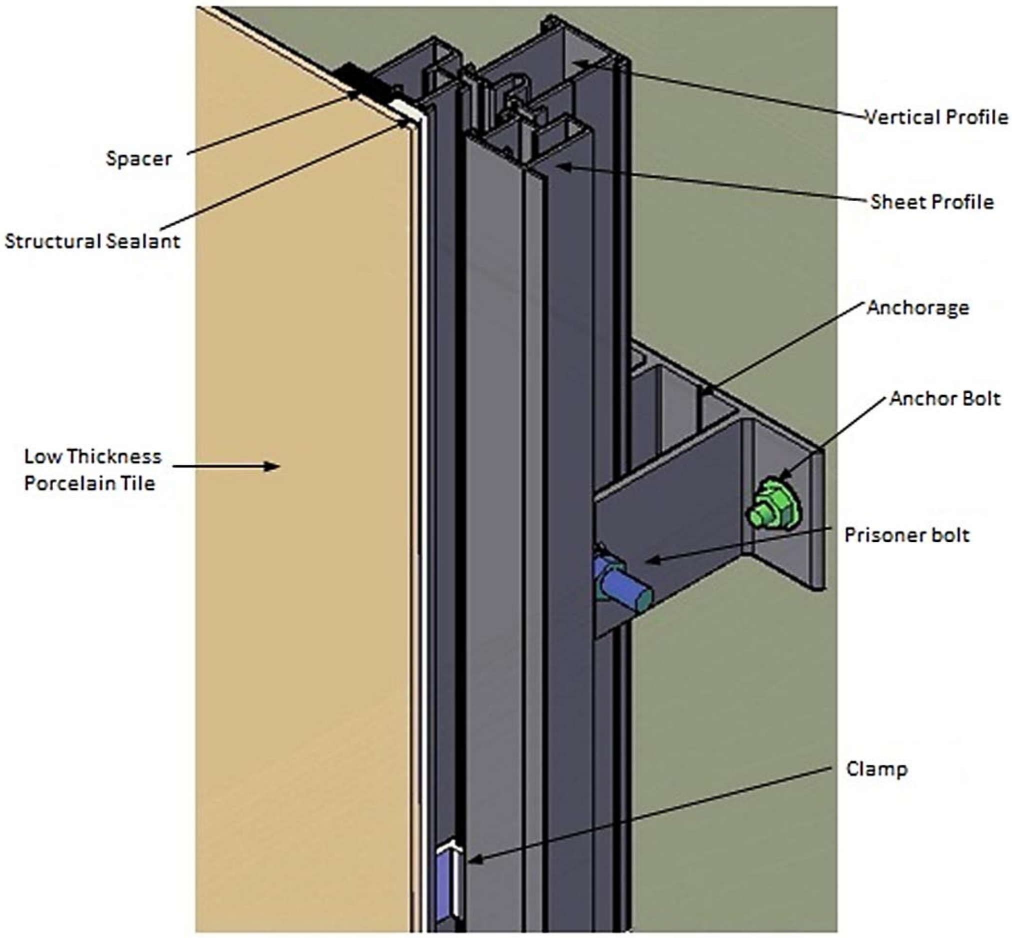

Figure 7 - Fixing System by clamps

2.1. Wind loads– NBR 6123 (1988)

For the sizing of the ventilated façade, the loading was calculated that is caused by wind, according to NBR 6123 (1988). Figure 8 shows a map with the basic wind speeds in the regions of Brazil.

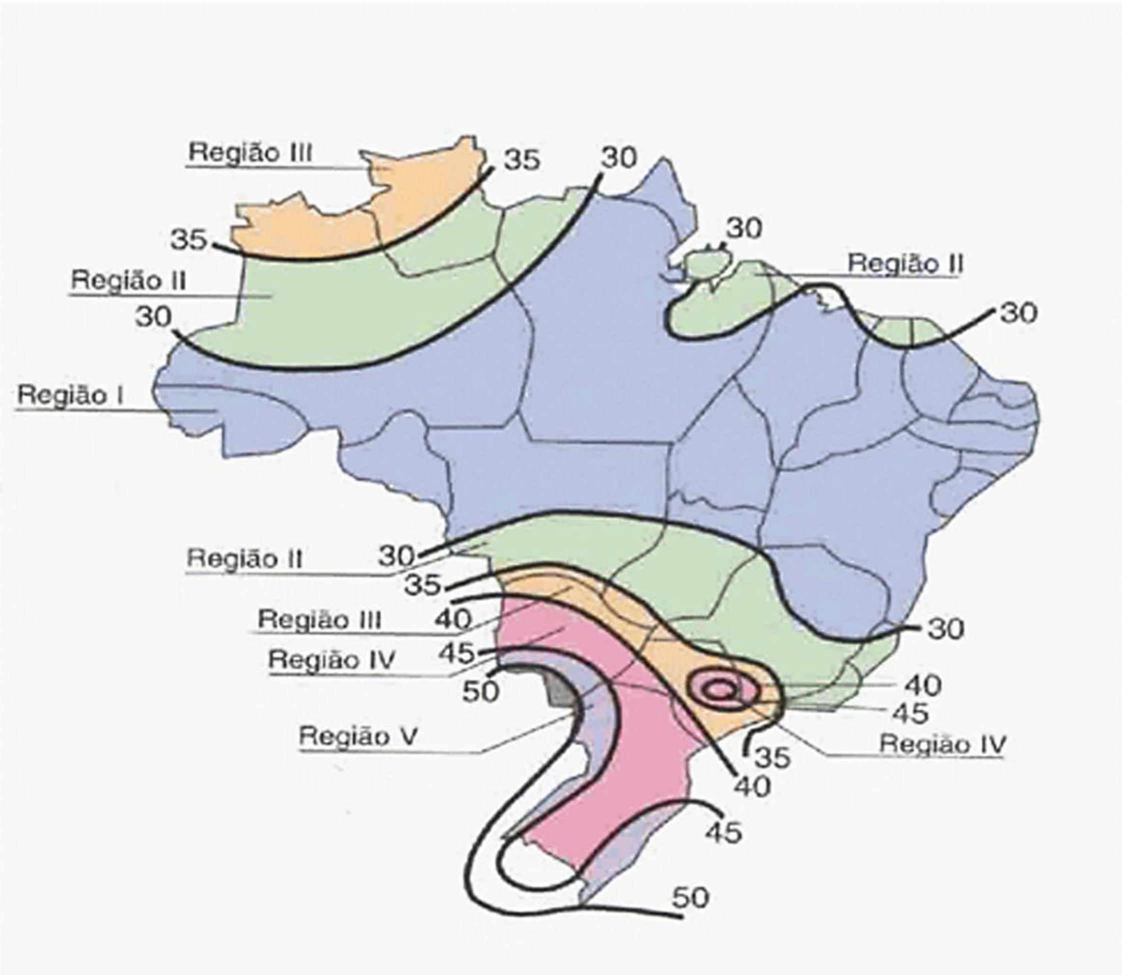

Figure 8 –Map of basic wind speed; "vo" in m/s no Brazil (NBR 6123,1988).

First of all, a basic wind speed of 50m/s was adopted. Thus, a test pressure of 2001.04 N/m² was found. The recommendation of NBR 10821 (2000), whose testing pressure is 1800.00N/m for curtain walls, was followed. Thus, for the façade that has been studied here, this value for the design of the construction system was considered. We carried out a verification even considering the basic wind speed equal to 45m/s, since this rate covers almost the entire Brazilian territory and a test pressure of 1620.84 N/m² was found. It was therefore concluded that the test pressure used in this work is in accordance with the specifications.

2.2. Structural behaviour

For the dimensioning of the vertical and horizontal profiles it was considered that the structure loading had a trapezoidal geometry, since the efforts are not concentrated in the whole area of the profile. The recommendations of NBR 10821 (2000) were followed. Figures 9 and 10 depict the trapezoidal loading for vertical and horizontal profiles, respectively.

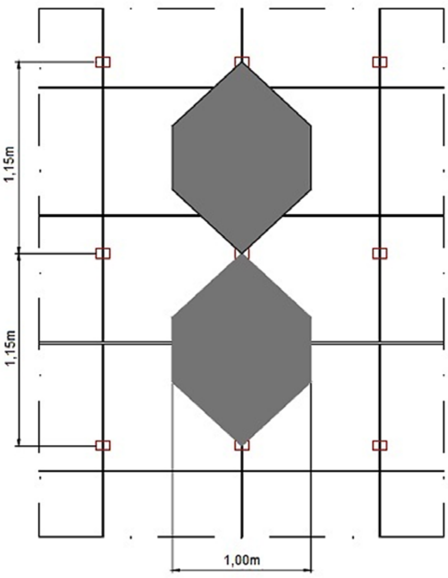

Figure 9 – Loading on the vertical profile.

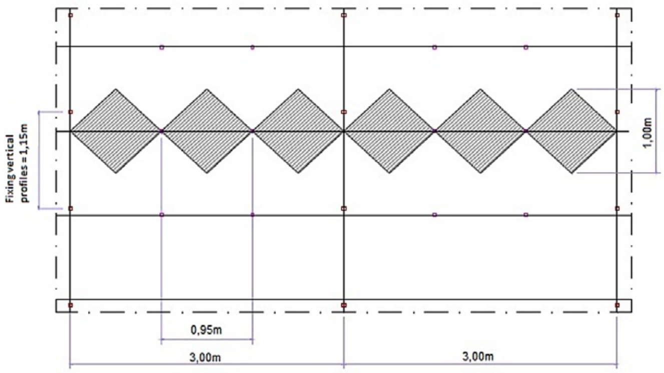

Figure 10 – Loading on the horizontal profile.

The vertical or horizontal profile receives evenly distributed loads as a bi-supported scheme.

Through the structural behaviour, it was determined that the vertical profiles should be fixed by anchorages to the base of the building structure at intervals of up to 1.15 m. The horizontal profiles needed to be fixed by means of anchoring at least every 0.95 m.

The following data are necessary for structural analysis:

- <u>Distance Supports:</u>

- Vertical profile – A = 1.00m

- Horizontal profile – A = 1.00m

- <u>Distance axis:</u>

- Vertical profile L = 1.15m

- Horizontal profile – L = 0.95m

- Test section area:

Mathematically, the area of the section was determined from the following expression:

$$S_m = (H - b/2) \times b$$

- Vertical Profile:

$S_m = (1.15m - 1.00m/2) \times 1.00(m)$
$S_m = 0.65\,m^2$

- Horizontal Profile:

$S_m = (0.95m - 1.00m/2) \times 1.00(m)$
$S_m = 0.45\,m^2$

- Test Pressure:

$P_e = 1800.00\ N/m^2$

- Total loading on the section:

- Vertical Profile:

$Q = 1800.00\ (N/m^2) \times 0.65\ (m^2)$
$Q = 1170.00\,N$

- Horizontal Profile:

$Q = 1800.00\ (N/m^2) \times 0.45\ (m^2)$
$Q = 810.00\,N$

- Distributed load:

- Vertical Profile:

$$q = \frac{1170.00(N)}{1.15(m)}$$

$q = 1017.39\,N/m$

- Horizontal Profile:

$$q = \frac{810.00(N)}{0.95(m)}$$

$q = 852.63\,N/m$

- Elasticity modulus of aluminium:

$E = 70 \times 10^9\ N/m^2$ (70GPa)

- Allowable tension of aluminium alloy 6060-T5:

$\sigma_{adm} = 75 \times 10^6\ N/m^2$ (75MPa)

- Linear thermal expansion coefficient

$\alpha = 24 \times 10^{-6}\ °C^{-1}$

Calculation of maximum allowable deflection:

$$\delta_{adm} = \frac{L}{175} \leq \quad 2\,cm$$

- Vertical Profile:

$$\delta_{adm} = \frac{115\,(cm)}{175}$$

$$\delta_{adm} = 0.66\ cm \quad (0.0066\ m)$$

- Horizontal Profile:

$$\delta_{adm} = \frac{95\,(cm)}{175}$$

$$\delta_{adm} = 0.54\ cm \quad (0.0054\ m)$$

Minimum Moment of inertia:

$$D_{máx} = \frac{5}{384}\frac{qL^4}{EI}$$

- Vertical Profile:

$$J_x = \frac{5}{384} x \frac{1017.39\,(N/m) x\ (1.15\,m)^4}{70x10^9 (N/m^2) x\ 0.0066\,(m)}$$

$$J_x = 5.0150x10^{-8}\,m^4$$

- Horizontal Profile:

$$J_y = \frac{5}{384} x \frac{852.63\,(N/m)\ x\ (0.95m)^4}{70x10^9 (N/m^2)\ x\ 0.0054\,(m)}$$

$$J_y = 2.3922x10^{-8}\,m^4$$

Minimum resistant moment:

The equation to define the active tension of bending is calculated by the resistance of materials as below:

$$\sigma_f = \frac{M_{max}}{I} x\ y$$

To deduce the equation for the resistant moment, (W) is calculated as:

$$W = \frac{qL^2}{8\ \sigma_{max}}$$

- Vertical Profile:

$$W_f = \frac{1017.39\,(N/m) x\ (1.15\,m)^2}{8x75x10^6 (N/m^2)}$$

$$W_f = 2.2425x10^{-6}\,m^3$$

- Horizontal Profile:

$$W_f = \frac{852.63\,(N/m) x\ (0.95\,m)^2}{8x75x10^6 (N/m^2)}$$

$$W_f = 1.2825x10^{-6}\,m^3$$

Linear thermal expansion:

$$\Delta L = \alpha L_o \; \Delta T$$

- Vertical Profile:

$$\Delta L = 24x10^{-6}(^oC^{-1})x1.15(m)x\ (45^o - 0^o)$$
$$\Delta L = 24x10^{-6}(^oC^{-1})x\ 1.15(m)x(45^o - 0^o)$$
$$\Delta L = 1.242x10^{-3}\,m\ (0.1242\,cm)$$

- Horizontal Profile:

$$\Delta L = 24x10^{-6}(^oC^{-1})x0.95(m)x(45^o - 0^o)$$
$$\Delta L = 24x10^{-6}(^oC^{-1})x0.95(m)x(45^o - 0^o)$$
$$\Delta L = 1.026x10^{-3}\,m\ (0.1026\,cm)$$

Structural analysis of the vertical and horizontal profiles (Aluminium Alloy = 6060 T5):

- Vertical Profile:

$J_x = 5.6589x10^{-8}\,m^4$
$J_y = 2.5607x10^{-8}\,m^4$
$W_x = 2.9873x10^{-6}\,m^3$
$W_y = 1.5680x10^{-6}\,m^3$

- Horizontal Profile:

$J_x = 4.6071x10^{-8}\,m^4$
$J_y = 2.7819x10^{-8}\,m^4$
$W_x = 2\ 7100x10^{-6}\,m^3$
$W_y = 1.6364\ x10^{-6}\,m^3$

Maximum deflection in vertical and horizontal profiles:

- Vertical Profile:

$$\delta f = \frac{5}{384} x \frac{1017.39\,(N/m)\ x\ (1.15\,m)^4}{70x10^9(N/m^2)\,x\ \ 5.6589x10^{-8}\,(m^4)}$$
$$\delta f = 0.0058\,m$$
$$\delta f \leq \delta adm$$
$$0.0058\,m < 0.0066m$$

- Horizontal Profile:

$$\delta f = \frac{5}{384} x \frac{852.63\,(N/m)x\ (0.95m)^4}{70x10^9(N/m^2)\,x\ \ 2.7819x10^{-8}\,(m^4)}$$
$$\delta f = 0.0046\,m$$
$$\delta f \leq \delta adm$$
$$0.0046\,m < 0.0054\,m$$

Active tension in vertical and horizontal profiles:

- Vertical Profile:

$$Mf = \frac{1017.39\,(N/m)x(1.15m)^2}{8}$$
$$Mf = 168.19\,N.m$$
$$\sigma f = \frac{168.19\,(N.m)}{2.9873x10^{-6}\,(m^3)}$$
$$\sigma f = 56.30x10^6\,N/m^2$$
$$\delta f \leq \delta adm$$
$$56.30\,MPa < 75.00\,MPa$$

- Horizontal Profile:

$$Mf = \frac{852.63\,(N/m)x(0.95m)^2}{8}$$
$$Mf = 96.19\,N.m$$
$$\sigma f = \frac{96.19\,(N.m)}{1.6364x10^{-6}\,(m^3)}$$
$$\sigma f = 58.78x10^6\,N/m^2$$
$$\delta f \leq \delta adm$$
$$58.78\,MPa < 75.00\,MPa$$

Bending resistance of the low-thickness porcelain tile:

The dimensioning of the low-thickness porcelain tile was performed by calculating the bending resistance. Please see the low-thickness porcelain tile information as below:

- Bending resistance = $50x10^6 N/m^2$ (50MPa)
- Thickness = 3.5 mm;
- Size = 3x1m;
- Weight = $8kg/m^2$

According to the wind loading, the following values were found:

- Wind Load = 1800.00 N/m or 1.8 kN/m^2
- Distributed load = 1.8 kN/m^2 x 3m (width of influence of the piece) = 5.4 kN/m.

The low-thickness porcelain tile must receive the sheet profile, as a framework. Some supports on the back of the low-thickness porcelain tile are added to avoid the bending of the piece. These supports are composed of T-profiles. With regard to the resistance of the materials, the active tension must be less or equal to the resistance tension, so the distance of the supports was determined (every 0.75m).

The main loading on the low-thickness porcelain tiles is the wind. For the calculation, a beam with five supports was considered.

The maximum moment is given in the support in the central part of the piece (low-thickness porcelain tile), with the value of 0.30 kN.m (300.00 N.m).

Through the calculating of the moment of inertia, the resistance section of the piece of the low-thickness porcelain tile was determined, in order to achieve the allowable bending resistance.

Moment of Inertia:

$$I = \frac{bh^3}{12}$$

$$I = \frac{3.00(m) \times (0.0035m)^3}{12}$$

$$I = 1.0718x10^{-8} m^4$$

Bending tension (active):

$$\sigma_f = \frac{M_{max}}{I} \times y$$

$$\sigma_f = \frac{300.00(N.m)}{1.0718x10^{-8}(m^4)} \times 0.00175(m)$$

$$\sigma f = 48.98x10^6 N/m^2$$

$$\sigma_f \leq \sigma_r$$

$$48.98 MPa < 50.00 MPa$$

Dimensioning of the structural sealant:

The use of a structural sealant to join the sheet profile and the low-thickness porcelain tile was defined. This structural sealant consists of a single-component polyurethane and the cure is accomplished by a chemical alteration caused by moisture in which a permanent elastic product is formed. It adheres to a variety of materials such as plastics, metals, glass fibers, ceramics and wood. They are formulated to a wide range of hardness, open times and various properties for different applications. The cure of the sealant is given for 24 hours. Tests of tensile and shear strength were carried out. The tests are shown in the figures 11, 12 and 13. The tests were carried out according to ASTM D-897.

Figure 11 – Samples.

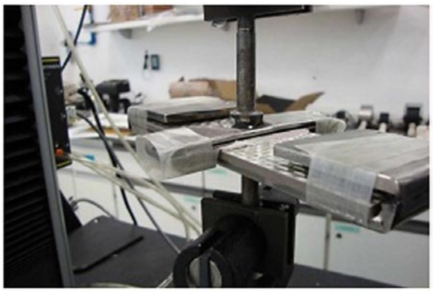

Figure 12 – Tensile strength.

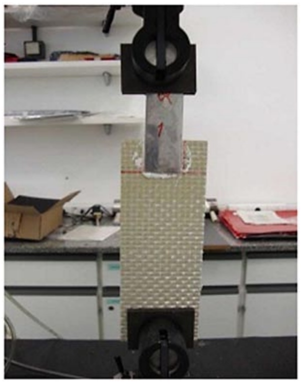

Figure 13 – Shear strength

The structural sealant showed a minimum tensile strength of 0.38 MPa and shear strength of 0.77 MPa, so both resistances are in accordance with the specifications for sealants.

In the tensile strength of the sealant, there was no detachment of the metal sheet but there was a fracture of ceramic tile, so it means that the sealants are compatible with the back of low-thickness porcelain tile (fiberglass). In the shear strength, it was possible to determine the maximum tension, when the detachment of the sheet metal occurred. Figures 14 and 15 present the tensile and shear graphs, respectively.

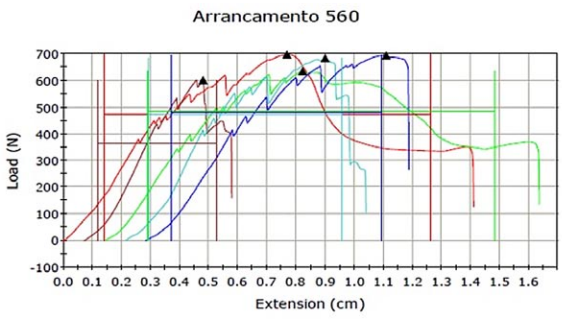

Figure 14 – Tensile.

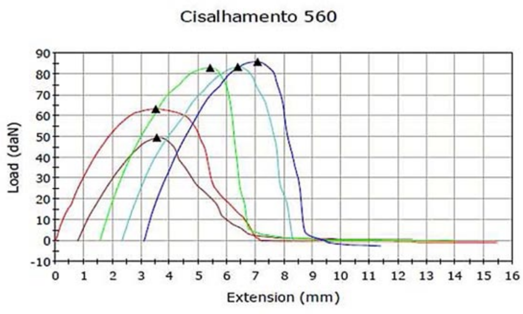

Figure 15 – Shear.

In the tensile test, there was a maximum length of 1.1mm when loads of 700N were applied and in the shear test, there was a maximum length of 7.5mm with loads of 850N. It shows that the sealant stretched before rupture occurred.

3. CONCLUSION

The sizing of the ventilated façade that has been studied here was characterized by an auxiliary aluminium substructure, low-thickness porcelain tile and structural sealant. All specifications were in accordance with the technical standard established by the standards. Also, guidelines of international companies that have worked with this technology for a long time were adopted.

The wind load on the façade and the structural behaviour of the vertical and horizontal profiles were determined. The maximum allowable deflection, minimum moment of inertia, minimum resistance moment and linear thermal expansion were verified. The structural data of these profiles were assessed, verifying compliance with specifications, by evaluating the results of maximum allowable deflection and active tension.

The subject studied in this paper has excellent growth prospects; as it is part of a global trend towards the use of industrial systems in civil buildings. In the future, there will be different buildings with ventilated façade systems, once they provide a better performance compared to traditional systems.

Thus, the appreciation of the ceramic tile and the opportunity to launch new projects and products will emerge in the market, as well as the development of buildings more suited to specific environments.

The aim of this study is to apply this technology of ventilated façades within the Brazilian ceramic tile industry. The ventilated façade system developed in this study has been commercialized by Eliane Ceramic Tile Company.

REFERENCES

[1] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 10821: Caixilhos para edificação. Rio de Janeiro, 2000.

[2] ______. NBR 6123: Forças devidas ao vento em edificações. Rio de Janeiro, 1988.

[3] AMERICAN SOCIETY FOR TESTING AND MATERIALS.ASTM D-897. Standard Test Method for Tensile Properties of Adhesive Bonds. Conshohocken-PA, 2008.

[4] BELMETAL. Catálogo Linha Offset: sistema modular de fachadas. São Paulo. Available at http://www.belmetal.com.br. Acessed on 01 August 2010.

[5] CAIXILHARIA básica para vidraceiros. Tecnologia & Vidro. São Paulo, 3-7 ed. Cap. II – VI, Apr./Feb./2000.

[6] CRASTA, Gian Paolo. 3mm: taking up the challenge. Ceramic World Review. Italy, n.73, 2007, p.150-159.

[7] HIBBELER,R.C. Resistência dos materiais. 3rd ed. Rio de Janeiro: LTC, 2000, 701p.

[8] KISS, Paulo. Pulmões prediais. Téchne. São Paulo, v.8, n.39, p. 36-38, Mar./Apr. 1999.

[9] LOW Thickness Ceramic Tiles. Tile International. Italy, p. 66-77, Feb. 2010.

[10] SANTOS, Luiz Carlos. Fachadas de alumínio: como alcançar um desempenho eficiente em alumínio. Contramarco & Companhia. São Paulo, n.55, p.28-37, set/out. 2005.

[11] TIMOSHENKO, Stephen P. Resistência dos materiais. 3rd ed., v.1. Rio de Janeiro: Ao Livro Técnico S.A, 1973, 451p.