DESIGNING CERAMIC TILE BUILDING FAÇADES

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ABSTRACT

Although ceramic tile and adhesive mortar manufacturing has undergone extensive development in the last few years, very little attention has been given to the design process. A well-defined tile façade system with all the necessary details is rarely suitable.

Nowadays, great responsibility can be attributed to the importance of having the right information at the right moment on the job site. It is very common to see building companies and contractors deal with confused and incomplete information.

Workmanship is also a problem with regard to the performance of ceramic tile façade systems. In Brazil, most of the knowledge about tile working seems to be lost. Italian and Portuguese masons and tilers of the past have not perpetuated their abilities. Engineers and architects also have to deal with new materials technology, including ceramics of very low absorption, polymeric mortars and high performance concrete structures with different mechanical characteristics.

This new context may explain the large number of pathologies we can see in our façades. Different situations demand adequate design and appropriate methods of application. These should include the right specification of materials, design detailing and training programs.

This work proposes a method of ceramic tile building façades design, presenting the guidelines and parameters necessary to organise the tiling work on the façade and avoid inadequate decisions on the job site.

The most important design parameters are discussed, including building movements, control joints and the flexibility of adhesive mortars. A couple of cases are studied to demonstrate how useful good desing is on the job site. Some examples of detailing and façades results are shown.

1. INTRODUCTION: DESIGN AS A PART OF A PRODUCTION SYSTEM

With the establishment of a new competitive market, in building construction it is essential to reach efficient, adequate results to conquer and maintain customers. A very strong tendency can be verified in a search for engineering system solutions dedicated to the production of different parts of the building. This search, however, can not disregard performance of the construction as a whole. Engineering solutions should necessarily also consider quality assurance, productivity improvement and better costs-benefits relations, in all the decisions along the processes of design.

The development of production systems, which consider in an efficient way all these requirements together, is the new challenger of the Brazilian market. Production systems should present, through an integrated and consolidated plan, engineering solutions characterised by specific technology of production, product design and process design. These features should involve the organisation of workmanship, materials, tools and equipment and all technical assistance required.

The design process should be considered as a part of the system and system selection is the most important part of it. Therefore, two levels of decision are basically found: a strategic level and an operational level. At the strategic level the designer must concern himself with the selection of products and production process among all those available. After the definition of products and processes, decisions take an operational character where materials, methods and techniques are defined. At the operational level, the designer must answer the following fundamental questions about the production:

- Which are the most adequate materials to the production?
- What are the recommended construction techniques?
- Which are the necessary construction details?
- Which are the most adequate tools and equipment to be used?
- What are the control requirements to be observed?
- What is the best sequence to be used?
- How must the production team proceed if problems occur?
- What are the possible alternatives available?
- What are the standards suitable for each case?
- How should the system be used and maintained?

2. DESIGN OF CERAMIC TILE BUILDING FAÇADES

Ceramic tile rendering must be considered as a system made up of different layers of materials that present different properties. Therefore, in order to understand its behaviour, it is necessary to observe not only the performance of each layer separately, but also the system as one single body, from the inner layer (framework or masonry) to the outer layer (ceramic tile and joints).

To build a ceramic tile façade, the constructor needs a wide range of information that allows obtaining adequate productivity, quality and costs to each particular situation. Guidelines and parameters that make the organisation of production easier are indispensable to reach expected results.

Based on its economic importance or based on its market share, the ceramic tile façade has a remarkable position. A recent research considering construction companies that work with medium and high patterns of enterprise has shown that a ceramic tile area is used in approximately 50 % of home buildings and about 40 % of office building (MORAES, 1997).

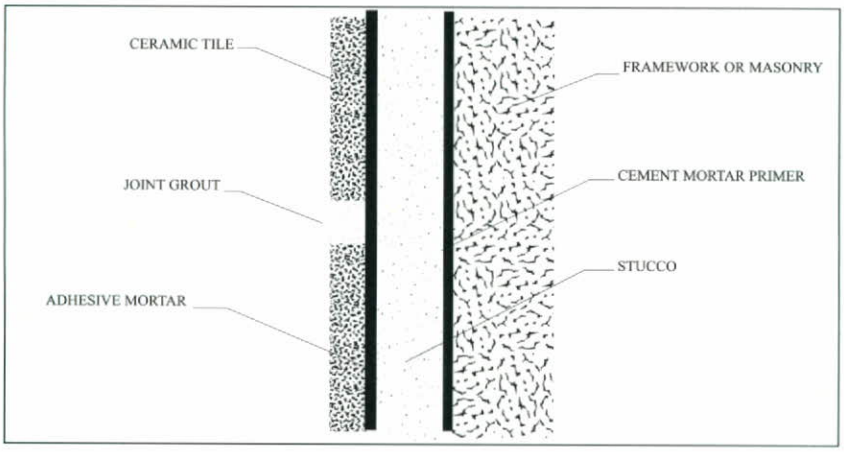

***Figure 1**. Elements and layers of an adhered ceramic tile façade.*

Most of the experiences of preparing ceramic tile façade design, which are considered in this paper have arisen from consulting requests of constructions companies. These companies have a very clear objective: they wanted to avoid problems of ceramic tile façade pathologies that have occurred in the past. An analysis of these cases has allowed the authors to conclude that the design process involves between 2 to 10 % of recovering costs, and 1 to 4 % of production costs, including job testing and workmanship training.

Although the experiences related here are very recent (the oldest case where façade design was done took place only four years ago- see Figure 4), the results can be considered of great importance.

Tiling design should not be considered only a group of graphics elements that includes plans, schemes and detailing. Design also involves questions of fundamental engineering techniques and particularities of each building. Two groups of different kinds of activities usually occur in the operational phase of design process: study of variables and parameters related to the façade of the building and decision making.

At the present time - where ceramic systems are still not available in the Brazilian construction market - the main activities of the design process are:

VARIABLES OF DESIGN PLANNING	PRE-EXISTING LOCAL CONDITIONS	VARIABLES OF THE CERAMIC TILE ITSELF
• Architecture design • structural framework design • masonry and partitions design • window frame design • financial and time resources	• ceramic tile support surface conditions • ceramic tile support movements • local weather conditions	• ceramic tile movements • previous specification of materials

***Table 1.** Operational activities of ceramic tile design process:*

MATERIAL DEFINITION	CONSTRUCTION TECHNIQUE AND DETAILING DEFINITION
• ceramic tile material	• support surface priming techniques
• priming material of support surface	• stucco construction techniques, including joints and reinforcements
• stucco support rendering	• tiling setting construction techniques
• tiling setting material	• tiling jointing construction techniques
• tiling joint filler material	• sealant application techniques
• control joints sealant.	• specific façade detailing
	• quality control criteria
	• production team training program
	• auditing design criteria.

***Table 2**. Operational activities of ceramic tile design process: decision making.*

3. SELECTION OF BUILDING FAÇADES SYSTEMS AND PRODUCTS

Selection of ceramic tile for façades should take into consideration a range of variables that allow carrying out the requirements defined by the designer. Aesthetics and costs are always to be observed. However, in order to reach durability and optimised cost-benefits relation, many others variables should be considered. It is not usually easy to reach this aim because it is necessary to understand a wide range of information, taking into consideration both architecture and engineering previous experience, sometimes very difficult to find in one single person.

A summary follows of the main criteria that should be considered in the selection of building façades systems and products:

Economic and market criteria:
- acquisition costs
- maintenance costs
- economic risks
- supply risks
- delivery time
- economic enhance of building façade
- imported dependence
- life time of façade
- quality assurance
- acquisition facilities

Engineering performance criteria:
- structural behaviour
- fire safety
- thermal-acoustic behaviour
- water and air tight
- durability

Construction criteria:
- facility of production

- productivity
- availability of equipment
- availability of workmanship
- interference in the rest of the job site programming
- modularity
- possibility of correction of fails
- degree of interaction with other parts of the building

Aesthetic and culture criteria:

- appearance enhancing
- composition patterns facility
- capability of keeping original appearance
- adequacy to the architectural style
- adequacy to the local cultural

Use and maintenance criteria:

- need and facility of cleanness
- period of maintenance
- facility of changing pieces
- availability of product for reposition
- facility of reposition and recovering
- risks of human accidents
- technical assistance reliability.

In order to organise the selection of products and systems, designers can establish rating criteria to evaluate, the greater or lesser importance of a variable. Through the organisation of benchmarks, selection becomes easier. Tables can order precedence for each particular situation. Benchmarks have been used very successfully, specially when a large range of variables should be considered.

4. REQUIREMENTS OF THE CERAMIC TILE BUILDING FAÇADE

In order to assure quality performance, ceramic tile to façade must fulfil a variety of specific requirements, considering every step of the design process. Accurate definition of these requirements demands an overall point of view that includes not only the knowledge of tile system layers characteristics, but also the understanding of the behaviour of the building as whole.

In order to facilitate understanding of ceramic tile system behaviour, we divide it into the three categories described as follows:

- **protection requirements** - ceramic tile façade must work as a protection of building envelope elements and structures against deterioration. These requirements are associated with the durability of building and its lifetime. Therefore, ceramic rendering protects the building from environment aggressive agents.

- **envelope requirements** - besides protection requirements of building façades, ceramic tile system must improve envelope elements performance (masonry is the most common in Brazil), including: thermal and acoustic insulation, water and air tight and fire safety.

- **final aesthetics requirements** - improve aesthetics of façades, enhancing building appearance is one of the basic requirements of ceramic tile. Façade aesthetics can also be evaluated through objective ways. Visual harmony, texture, brightness and colour, geometric accuracy and the capability of keeping original appearance can be used as parameters to evaluate aesthetics. Considering these ideas one may take into account, for instance: alignment of tile joints and corners, plane of tile surface, non existence of fading and cracks, colour changing and staining.

Besides all those requirements there are others that can be taken into consideriation depending on the particularities of the case. Sanitary, hygienic and security can be considered important features.

Figure 2. *General failure of ceramic tile façade. Extruded stoneware were used with an ordinary mortar. Weather conditions during summer are very severe. Temperature above 40°C is usual. Control joints were built after the bond had failed.*

The non-observation of the whole features together may cause serious problems on ceramic tile building façades, usually difficult to deal with and expensive to repair. Figure 2 shows an example of a building façade where the misunderstanding of minimum requirements is clear.

5. MOVEMENTS IN CERAMIC TILE FAÇADES

The study of building movements that can interfere in the performance of ceramic tile is one of the most important features of tile design process. These movements have both internal and external origin and can be classified as shown in Table 3.

MOVEMENTS DUE TO PERMANENT LOAD	
Own weight of ceramic tile rendering	• vertical load caused by the sum of masses of ceramic tiles, adhesive mortar and grout joint.
MOVEMENTS DUE TO VARIABLE LOAD	
Wind and seismic load	• movements caused by the action of wind on façades, vibrations and seismic loads transferred from the ground.
MOVEMENTS DUE TO THE ACTION OF TEMPERATURE	
• movements caused by temperature changes that effect ceramic tile and others layers of the system, mainly concrete, metal and masonry support. Very important because of thermal shock, specially when tiles of dark and dull colours are used.	
MOVEMENTS DUE TO THE ACTION OF HUMIDITY	
Drying shrinkage	• reversible shrinkage of volume that occurs in early ages and irreversible shrinkage that occurs time after time through the years. Both are caused by volume changes due to changes in water content of materials. Very important where Portland cement is used because of the hydration, including concrete, masonry, stucco, mortar and grout.
Expansion due to humidity	• expansion caused by water when inside the pores of materials. Depending on the expansion intensity degradation can occur. Very important when materials show high degree of absorption, including regular and aerated concrete masonry. Because of this, only ceramic tiles of low absorption are recommended for façades.
MOVEMENTS DUE TO STRUCTURAL DEFORMATION	
Deformation in early ages	• deformation caused by the weight of the framework, its infillings, partitions and coverings in the early ages. Accidental load also contributes. Very important for new concrete structures, specially immediately after removing formwork.
Slow and plastic deformation throughout time - creep	• deformation caused by weight of framework, its infillings, partitions and coverings acting throughout time. Accidental load also contributes. Very important in concrete structures made with high performance concrete where beam and slabs have large spans.
MOVEMENTS OF FOUNDATIONS	
• movements caused by accommodation of foundation, normally stable after usage loading. Very important where ground conditions shows instability. Usually critical also for the stability of structure, infillings and coverings.	

Table 3. *Classification of internal and external movements that may interfere in the performance of ceramic tile façade systems.*

Depending on the case, one mechanism that generates movements becomes more important than another. Generally, however, the ceramic tile designer must pay careful attention to the possibility of thermal shock and hygroscopic movements. In the last few years structural deformations have usually been critical to ceramic tile, especially in high rise buildings. Drying shrinkage of masonry and stucco have to be always taken into consideration if cement based materials are used.

One of the most important problems regarding the performance of ceramic tile façades is to establish the magnitude of the movements that must be absorbed by the adhered tile system. In other words, the designer should be able to predict which is the necessary *flexibility* for the adhesive mortar and joint grout.

Several studies have been done with the aim of understanding this property. The work of the UNION EUROPÉENE POUR L'AGREMENT TECHNIQUE DANS LA CONSTRUCTION (1990) e RIUNNO & MURELLI (1992) deserve highlighting.

AKIAMA et al. (1997) also studied the flexibility of adhesive mortars. These authors propose a simplified testing method that gave good results. Mortars are evaluated through a factor F that can be used to classify flexibility. This subject is discussed more specifically in the paper *The Flexibility of Adhesive Mortars: An Experimental Study* included in the proceedings of Qualicer 98.

The specification of control joints is also related to the use of flexible adhesive mortars. Theoretically, a smaller number of joints can be used if a *flexible* mortar and a *flexible* grout are specified. However, up to the present time, there is still not an accurate recommendation or standardisation that demonstrates how to consider this influence. Therefore, design is usually based on previous experiences and very simplified mathematics calculations that do not consider one or more adhered layers working together.

6. ADHESIVE MORTARS FOR CERAMIC TILE FAÇADES

The Brazilian draft standard regarding the specification of adhesive mortars classifies this material according to the adhesive bond, open time and sagging. The draft is based on the CEN/TC 67 N.65 standard (EUROPEAN COMMITTEE FOR STANDARDISATION, 1995) and sets criteria for the testing of bond through directly testing tensile strength. Adhesive mortars are classified into three different types.

Property	Test Method	Unit	Adhesive Mortar Type			
	Draft		1	2	3	3 E
Open time	18:406.04-003	min	≥ 15	≥ 20	≥ 20	≥ 30
Bond strength at 28 days:	18:406.04-004					
	air cure	N / mm^2	≥ 0,5	≥ 0,5	≥ 1,0	≥ 1,0
	underwater cure	N / mm^2	≥ 0,5	≥ 0,5	≥ 1,0	≥ 1,0
	hot house cure	N / mm^2	-	≥ 0,5	≥ 1,0	≥ 1,0
Sagging	18:406.04-005	mm	≤ 0,5	≤ 0,5	≤ 0,5	≤ 0,5

***Table 4.** Mechanical requirements of adhesives mortars according to Brazilian draft standards (Associação Brasileira de Normas Técnicas, 1997).*

Basic differences are based on open time and bond strength. According to the draft, mortars Type 3 and 3-E have superior bond strength. Type 3-E has larger open time.

Adhesives mortars Type 1 are specified for internal uses while Type 2 for external. Table 4 shows this classification.

6.1. BOND STRENGTH

Bond strength can be considered the most important property of adhesive mortars. Bond strength depends not only the mortar itself but also on several other important variables, such as: absorption of ceramic tile, surface characteristics of substrate, weather conditions and workmanship quality.

The mechanical bond allows explaining the interaction between porous materials and cement based adhesives, such as ordinary adhesive mortars usually used for ceramic tile setting. In this case, bonding is achieved through the crystallisation of cement gel inside porous.

Mortar bond strength may be improved by the addition of polymers that allow gains in the mechanical bond and develop chemical adhesion too. The polymer amount defines how much adhesion can be set. Such mechanisms can explain, for instance, the adhesive bond of resin based adhesives to polished and non-porous materials. Table 5 shows typical values of bond strength obtained through tensile tests using different kinds of adhesive mortars to set different absorption ceramic tiles on cement based stucco.

ADHESIVE MORTAR TYPE	A III	BIa (porcelain)	BIa (porcelain stoneware)	BIb	BIIb	BIII
Ordinary mortar	2	5	5	5	5	5
Single component	5	10	10	10	10	15
Two component	5	10	10	10	10	12
Two component with the addition of 4 % of cement weight of acrylic resin	5	10	10	10	10	12

Table 5. *Typical values of tensile bond strength between adhesive mortar, ceramic tiles[1] and cement based stucco obtained from an experimental study[2] (N/mm²).*

The bond has to keep its strength during the lifetime of the building. Therefore, the designer must take into consideration that adhesives mortars may lose some bond strength on aging, especially those that have a low capacity of absorbing deformation and are subjected to intense fatigue and creep.

Not only tensile tests can be used to determine bond strength. This property can be evaluated through shear tests according to procedure describe in ANSI 118.4 (AMERICAN NATIONAL STANDARD INSTITUTE, 1992). In the case of building façades, shear strength can become critical, depending on the magnitude of different movements between masonry infilled framework and ceramic tile layer. Nevertheless,

[1]. Classification of absorption according do ISO DRAFT 13.006 (ISO, 1992).
[2]. Adapted from LORDSLEEM JR., A.C.; SOUZA, J.C.S.; MEDEIROS, J.S.; SABBATINI, F.H. *Resistência de aderência de revestimentos cerâmicos.* Anais do II Simpósio Brasileiro de Tecnologia de Argamassas. Salvador. 1977. p. 259-269.

the determination of how much bond strength is really required for each specific situation is a difficult question to answer.

6.2. DEFORMATION ABSORPTION CAPABILITY *(FLEXIBILITY)*

While hardening of Portland cement is taking place, adhesive mortar gains bond and mechanical strength. On the other hand, the layers of different material that make up an adhered ceramic tile system come to work as if they were only one. Because of that, interfaces and materials are subjected to movements that create stresses that must not exceed the material strength and bond between them.

Although influenced by different degrees of restriction, ceramic tile façades panels defined by control joints need to dissipate stress to keep adequate performance and avoid problems. Bond, however, is not the only property that matters. The ceramic tile system must absorb some degree of stress. Adhesive mortars, therefore, must be selected according to the situation that they are going to be subjected to. Sunbaked large panels of ceramic tile require more *flexibility* to avoid bond problems.

Cyclic load may cause damage too. Repeated movements of expansion and contraction can influence bonding and cause failure because of fatigue. *Flexibility* can also avoid these problems.

Adhesive mortars become *flexible* through the addition of polymers with elastomeric properties. Acrylics, styrenes and vinyls are polymers used with that purpose. On the other hand, polymers usually increase bond strength too. It is usual in Brazil to find adhesive mortars called *ordinary* or *flexible*. This classification is still confused because the flexibility concept of adhesive mortar is still not clear. Only adequate standardization based on research will solve this question.

To be considered *flexible*, adhesive mortars must satisfy requirements of minimum load and strain in flexion tests. The UNION EUROPÉENE POUR L'AGRÉMENT TECHNIQUE DANS LA CONSTRUCTION (1990) describes a procedure to evaluate the flexibility of adhesive mortars. The flexion test described uses a specimen where a 3 mm thick layer of mortar is set on a board of expanded polystyrene foam. As an indication, flexibility may be recognised if the failure load is equal to or exceeds 3 N, while the corresponding displacement must be equal to or exceed 5 mm.

6.3. OPEN TIME

Open time of adhesive mortars is an important characteristic to tile setting work on the job site. It can strongly influence the bond strength of ceramic tile. Open time is normally expressed in minutes, and establishes the time limit after spreading the mortar, within which tiles can be set without damage to bond.

Open time varies according to mortar dosage (mainly with type and amount of polymer), water absorption condition of substrate and water evaporation. This property is particular important in situations where façades are subjected to high temperature, low humidity and windy conditioning. The evaluation of open time of adhesive mortars is described in the standards, including CEN-TC 67C (ECS, 1993), ANSI A-118.1 C-5.4 (ANSI, 1992) and NBR PN 18:406.04-002 (ABNT, 1997).

6.4. CRITERIA FOR THE SELECTION OF ADHESIVE MORTAR

There are many adhesive mortars available in the Brazilian market. Different kinds of products can be found. Whatever the situation, the selection of adhesive mortars for façades must be an engineering matter. The designer must take into consideration at least the following features:

- characteristics of ceramic tiles (surface conditions, weight, colour, absorption, etc.);
- thickness and size of tiles;
- number and width of grout joint;
- use of control joints;
- surface characteristics of substrate;
- expected deformation of substrate (structural framework and infillings);
- local weather conditions (temperature, humidity, wind, freezing, pollution);
- weather conditions during tile work;
- position of ceramic tile façade.

Consideration of these variables makes the selection of adhesive mortars and grouts a complex matter. The designer must know not only a wide range of technical information about the materials, but also what the situation really requires. Accurate information about structural and infillings behaviour is, for instance, essential data to predict and avoid future problems.

Most of the time, *in situ* evaluation of application conditions is recommended. A precise description of local condition of application is necessary. It is obvious that this evaluation and detailing depends on how much risk should be considered. Lab tests and suppliers guarantees can be enough for certain cases. On the hand, correct adhesive mortar and grout selection is not enough to guarantee adequate behaviour of the whole ceramic tile. Actually, ceramic tile is just one element of a multilayer system where several parts of the building are involved (structure, infilling masonry, rendering and stucco).

7. FAÇADE CERAMIC TILE JOINTS

Joints are regular spaces between two tiles or tile panels that contribute to controlling movements and allow the assembly of different aesthetic patterns. Tile panels are usually divided by control joints which are the main responsible factors for the stability of the whole system.

Joints can be classified into two groups: setting or grout joints - those inherent to modular renderings - and movement joint - those responsible for absorbing stresses generated by contraction and expansion of the substrate, stucco and ceramic tile panels. Movement joints can be divided into two types: structural joints and control joints.

When control joints are used only to separate ceramic tile panels, they can be termed tile control joints. Joints used to separate different materials on façades are termed perimeter joints. Table 6 shows a possible classification of building joints.

- **settling or grout joints** — inherent of modular renderings, these joints contribute to control joints mainly if a low modulus filler is used. Aesthetics and constructability are important for this joints.
- **movement joints** — responsible to absorbing stresses generated by contraction and expansion of substrate, stucco and ceramic tile panels.
  - **structural joints** — main role is to compensate movements of building as a whole, specially framework movement. Ceramic tile joints must always respect these joints.
  - **control joints** — designed to control stresses due to the movements of the infillings, stucco and ceramic tile itself.
    - **tile control joints** — used only to divide ceramic tile panel
    - **perimeter joints** — used to separate ceramic tile from other different material on the façade, such as window frames or metal coverings.

Table 6*. Classification of building joints.*

7.1. BASIC PRINCIPLES FOR THE DESIGN OF CONTROL JOINTS

The most reasonable way to absorb stress caused by ceramic tile façade movements is to use control joints. The designer should consider all possible movements to specify the control joints for ceramic tile façades in order to guarantee their integrity throughout their life time.

Control joints are used to divide ceramic tile façades into panels to allow absorption of several different movements working together. Most of the time, control joints also divide the stucco on which ceramic tile is applied.

Although every façade has its particular situation, and the specification of control joints can vary, some guidelines for the design of control joints can be listed here. Observation of these guidelines, also based on experience and simple calculation, may help design specification. These are as follows:

- *pre-existing joints of the support* - structural joints, infilled masonry joints and stucco joints must be transferred to the ceramic tile layer. The geometry of this joint should keep the same up to the outer layer. Sealants should be compatible with the predicted largest expansion and contraction movements;

- *façades corners* - it is normally necessary to use tile joints where one side of a façade meets another. External and internal corners need joints;
- *interface between different material* - elements made of different materials show different movements, therefore a joint is recommended, for instance, between an aluminium window frame and ceramic tile. All façade elements that cause movement restriction to ceramic tile should be bounded by joints;
- *every floor level* - control joints should be used to control horizontal contraction and expansion of building façades. Joints should be positioned in the interface between masonry infilling walls and concrete structural elements such as beams and slabs. Horizontal control joints positioning may observe top of walls and bottom level of beam. This joint should align with the top level line of window frames;
- *parapets and façades projecting panels* - These elements are usually subjected to intense movements where cracks can occur. The designer must be able to predict where cracks may appear and locate control joints in these positions.

It is also necessary to determine width and depth of control joints in order to ensure their adequate behaviour in time. Joint width must compensate all façade movements working at the same time, while depth is related to width and depends on sealant type.

The use of mathematical calculations to predict movements of joints should be considered together with the capability of movement of sealant and facility of application. Based on these criteria, the minimum practical width of a joint is 10 mm. Smaller widths may hamper filling of joints since it is necessary to introduce a back rod and curl sealant.

MOST FAVOURABLE SITUATION	MOST UNFAVOURABLE SITUATION
• white and brilliant colours	• dark and dull colours
• façades sheltered from the sun	• sunbaked façades
• ceramic tiles with larger size inferior to 20 cm	• ceramic tiles with smaller size superior to 20 cm
• low modulus ceramic tiles	• high modulus ceramic tiles
• rigid structures	• very flexible structures
• façade panel with large openings	• façade panels without openings
• *flexible* mortars and grout	• ordinary mortar and grout
• masonry with minimum shrinkage	• masonry subjected to drying shrinkage
• low modulus stucco	• high modulus stucco

RECCOMENDATION	RECCOMENDATION
PANEL AREA ≤ 30 m^2 **LARGER SIZE ≤ 10 m**	**PANEL AREA ≤ 9 m^2** **LARGER SIZE ≤ 3 m**

Table 7. *Limit situations to the specification of horizontal and vertical control joints.*

Generally, not only horizontal control joints are necessary but also vertical control joints. Vertical joints are usually used to divide wide façade panels of ceramic tile. It is recommended not to exceed 4 to 6 m widths. In any case, the design must observe aesthetics. The combination of horizontal and vertical joints is important. One should pay attention to alignments with window frames and openings not only to save money and time but also to reach an harmonious result. The recommendations listed above may be conservative but a smaller number of joints may be used only based on solid calculation. The designer may use smaller panels when dark colour ceramic tiles are used. The same should happen when large size tiles are specified. Adhesive and grout mortars of improved *flexibility* may allow use of larger panels. Table 7 shows limit situations for the specification of control joint spacing.

7.1.4. SEALANT SELECTION

Performance of control joints depends on adequate design and construction. Ceramic tile façades control joints requires waterproofing. In order to avoid water penetration, the joint requires sealant protection. Sealant should be used to guarantee joint performance during life time. Polysulfide, silicone, polyurethane and acrylic sealants are products suitable for control joint treatment depending on the demands of each particular situation. These sealants usually do not require a previous primer. Primer application requires control and extra time for joint treatment and must be avoided. Silicones and polyurethane are examples of sealants used in Brazil for ceramic tile control joints. According to PANEK & COOK (1991) the designer should pay careful attention to a large number of properties, including:

- movement capability;
- hardness;
- solids content;
- resistance to heat aging;
- resistance to weathering;
- compression resistance;
- ultimate tensile strength and elongation;
- tensile adhesion;
- adhesion-in-peel;
- adhesion to porous and non porous materials;
- primer necessity;
- tack-free time;
- resistance to water;
- tear resistance;
- modulus of elasticity;
- colour retention
- staining of masonry and tile surface;
- cyclic tension and compression testing;
- creep, stress relaxation and recovery;
- application technique;

- shelf time;
- toxicity.

For the adequate selection of a sealant, the designer must analyse each product's advantages and disadvantages. Detailed information from manufactures is important. Certificates from independent laboratories may be requested. All data should be organised and updated because sealant technology changes a lot.

In the last few years the world market of sealants has been offering a notorious variety of products destined for specific situations. Nowadays, most kinds of sealants can be found in a variety of colours and durability. Some manufacturers declare a life time of 50 years. There are also hybrid sealants made from acrylic and silicone, urethane and polysulfide and many others.

8. EXAMPLES OF CERAMIC TILE FAÇADE DESIGN DETAILING

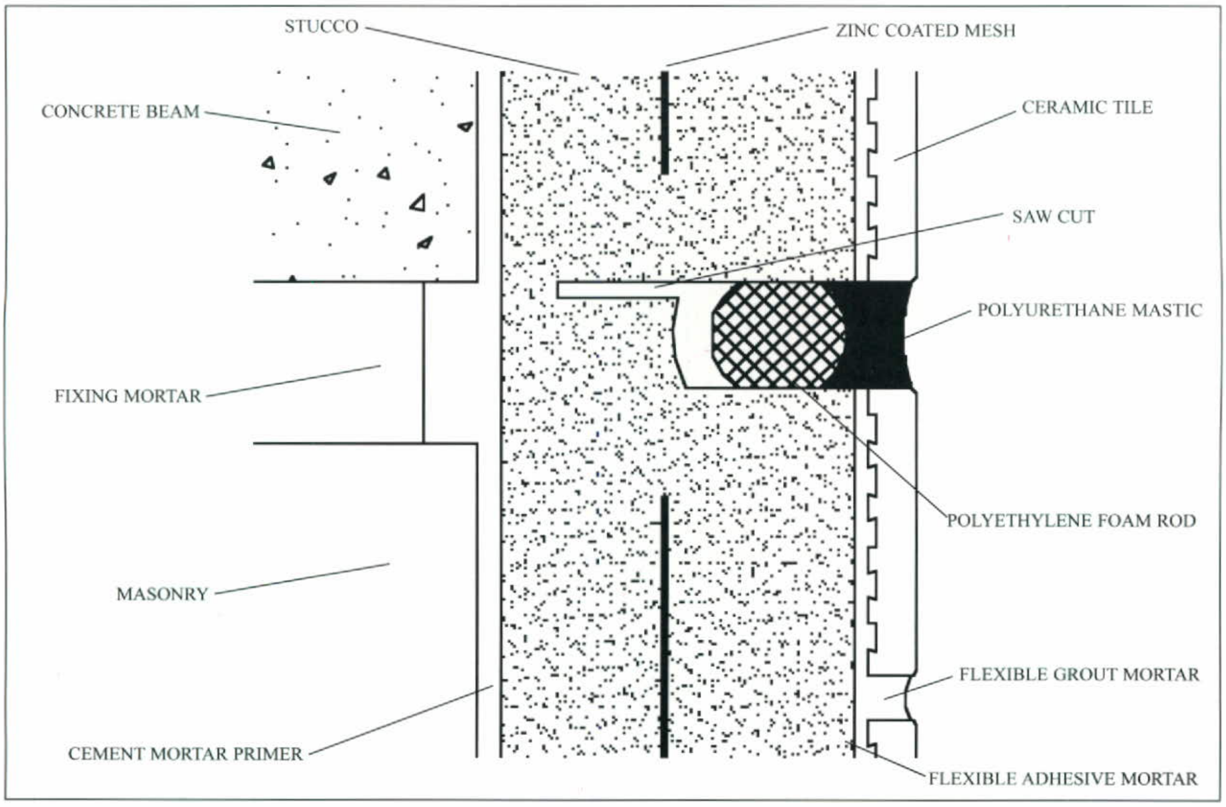

Figure 3. *Detail of horizontal control joint for an extruded stoneware tile façade.*

9. FINAL CONSIDERATION: A WAY TO IMPROVE CERAMIC TILE QUALITY

Based on previous experiences and considerations about the process of design, it is possible to assert that effective solutions for ceramic tile façades require a systematic approach that takes into consideration engineering analyses of a large number of requirements. On the other hand, engineering based analyses demands technological development and generation of ceramic tile systems of production. From our point of view, manufacturers of ceramic tile should lead this process.

Figure 4. Façade of a building where ceramic tile design has been used with success. Detail shows vertical and horizontal control joints.

This study may also conclude that ceramic tile systems should necessarily involve production technology and product design. Systems should facilitate selection of materials and construction techniques and methods in order to improve results.

In Brazil, ceramic tile systems with this approach are still not available. We believe that this is one of the most important reasons that explain why we still have a considerable number of problems. In general, the following situation can be found:

- most of the contractors are not professional;
- most of the materials suppliers do not assist construction firms as required;
- construction firms usually do not practice technical purchasing;
- customers are not conscious enough of their rights;
- designers and architects do not offer adequate design.

This reality mainly affects customers and constructors because, while the first feel the problems on their own properties, the second must usually accept the additional costs of maintenance, recovering and the possibility of harming their public image.

Ceramic tile system should be specific enough to attend the different requirements of building façades, specially regarding costs of construction and compatibility with others parts of the building - there are no systems dedicated to concrete structures or masonry either. We also believe that ceramic tile can work as a catalyst for actions to improve the quality of building construction as a whole, since its performance is fundamental to the success of the enterprise.

It is also important to emphasise that in any situation, the ceramic tile system should be adequate for the conditions of the local market. This is a necessary demand for the economic success of the system. Moreover, systems must be improved continuously through correction of failures in the process of design, production and utilisation.

We are firmly convinced that there is an enormous market available for the introduction of ceramic tile systems in Brazil. Many efforts, however, are neded to make it work. We can also see a strong tendency towards a market where construction firms would work in a sense of integrating different systems to produce their products.

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