DATA COLLECTION OF FIVE YEARS OF EXTERIOR FACADE PATHOLOGIES IN BRAZIL

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ABSTRACT

In this study we aimed to present the results of a data collection from 44 studies of ceramic tile installation pathologies that took place in Brazil from 1998 to 2003. We have collected data from structural systems, floor number, ceramic tile functional and aesthetic characteristics, and external wall cladding design and installation. Pathologies were observed in buildings with different number of floors. The large majority of them presented concrete structure with non-bearing walls. The ceramic tiles involved in pathologies were supplied by several manufacturers in Brazil with predominant size of 10 cm x 10 cm. They were conformed by pressing and their surfaces were glazed. The back side of most ceramic tiles had a dovetail configuration. In all the buildings the cladding was direct adhered using predominantly the thin bed method of installation. In less than 10% of the buildings, the joints width between tiles was less than 5 mm and in all the cases they were filled with based Portland cement materials. Horizontal movement joint was observed in only 1 out of 44 evaluated facades. Vertical movement joints were not verified. Ceramic tile surface cracking, efflorescences, deterioration of cement grouting material and staining from water repellent sealers were the major aesthetic defects. Regarding functional defects, delamination, bumping, falling of cladding sections and/or pieces, cracking, and movement joints sealants failure were mostly detected. Considering that delamination and bond failure are the number one concern and fear of owners, architects, engineers, and construction contractors, because they pose a serious risk to public safety, the causes of these defects were investigated. Important contribution was observed from ceramic tile moisture expansion, lack of specifications and experience in use of thin bed polymer modified cement mortars, and absence of means of controlling stresses induced by building movement and weathering (as movement joints).

1. INTRODUCTION

Ceramic tiles have been used for centuries for the exterior facades of buildings. The installation of tiles on exterior walls imparts both durability and aesthetic appeal to the facade and hence it has been a choice for buildings owners.

The most usual tile system for external cladding adopted in Brazil and also spread around the world comprises the tiles, a substrate, a necessary fixative to adhere the tiles onto the substrate and a grouting material to seal the pointing gaps between the tiles. Nowadays, this directed adhered system has a dispersive powder polymer modified mortar as the adhesive with the thin bed method in the installation of tiles. Figure 1 shows the typical external tile system generally found in Brazilian buildings.

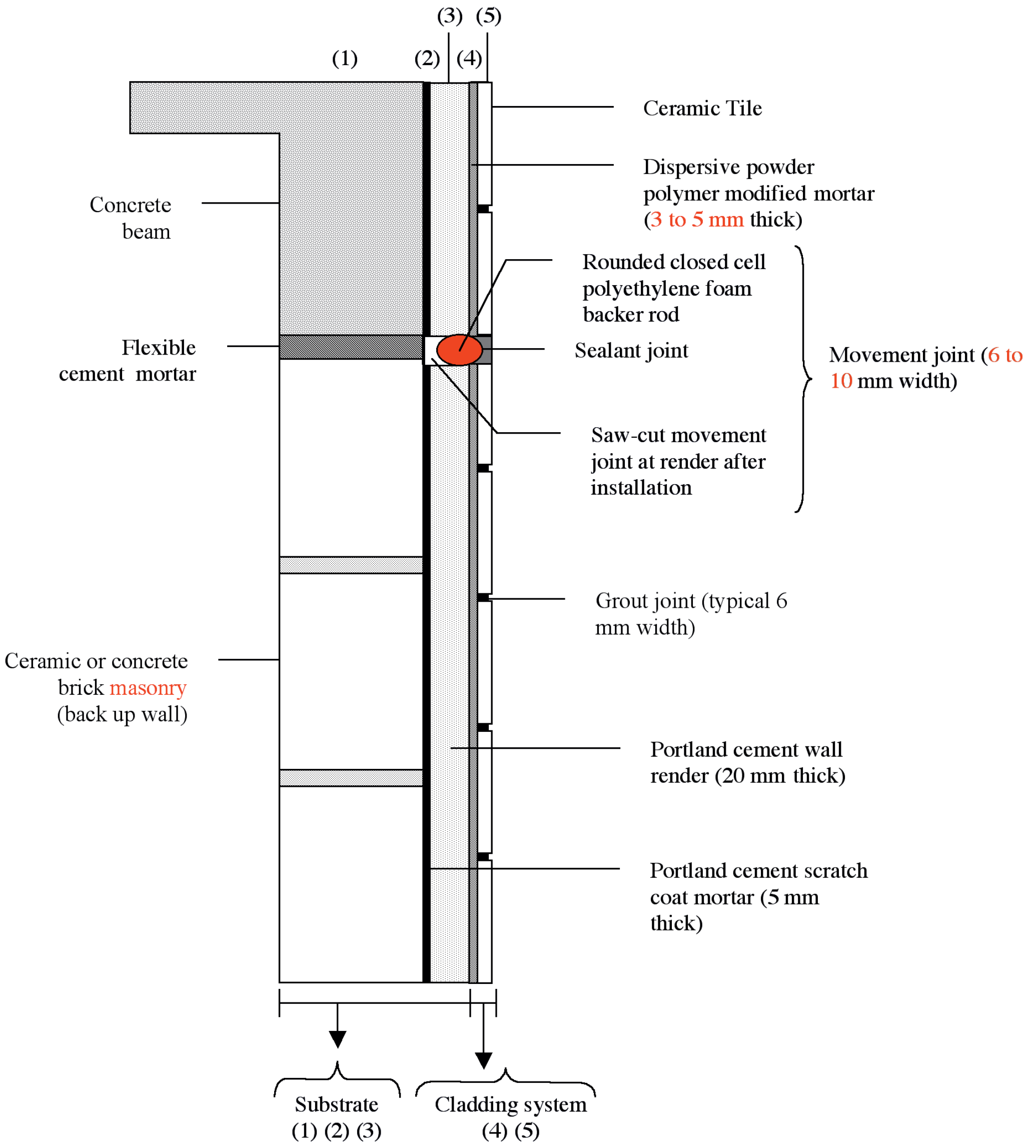


Figure 1. Typical tile system.

It was in the sixties when the dispersive powder polymer modified mortar was introduced at Brazilian market. However, its use as major adhesive in ceramic tile installation began in the middle of the 80's. The change from the cement mortar mixed with water, traditionally used as an adhesive for exterior ceramic tile, to the modified mortar has occurred without materials standards, design and tile installation as well without training and maintenance programs. Brazilian standard that outlines all materials and methods for external ceramic cladding system using modified mortars was published only in 1996 (NBR 13755/96) while the standard that specifies the adhesive requirements as a function of use was released in 1998 (NBR 14081/98). The consequence of the absence of standards specific to this new technology resulted in the occurrence of several pathologies.

The ceramic tile systems pathologies are, in general, a combination and confluence of several factors and rarely caused by a single mechanism. Some defects are only aesthetics while others, like bond failure, pose a serious risk to public safety. Other problem related to facade pathologies is the significant reduction of new buildings with tiled facades owing to the insufficient assurances provided by tiling performance. Ceramic tiles choice is being replaced by alternative materials and solutions which are capable of offering comparable visual appeal and equivalent functional performance.

Considering the effects of ceramic tile anomalies to the ceramic industry, building users and owners, as well the economic and environmental costs of repairing defective tiling, it is very important to obtain statistics data providing detailed information on the causes that originated tile pathologies. In this sense, the aim of the present paper is to present the results of a data collection from 44 studies of ceramic tile installation pathologies that have occurred in Brazil from 1998 to 2003.

2. EXPERIMENTAL PROCEDURE

The pathologies evaluation begins with a visual inspection on the building in order to characterize the edification, the facade and the anomalies. In this first moment, general information about the building is collected: number of floors, age, type of structural system (concrete or metallic frame or bearing walls) and material of back up wall (typically clay or concrete). Also, the major functional and aesthetics defects are identified. During this inspection, the ceramic tile data is obtained: forming process, manufacturer, size, colour, surface finishing, configuration of back side, deviations of size and presence of engobe contamination in tile back side. The features of grout joints (width, grout material, colour of grout, grout joints configuration) and movement joints (location, width, sealing material), as well, are identified. If detached pieces are observed, information about exceeded open time, coverage of adhesive behind tile, type and place of rupture (adhesive or cohesive) and tile back buttering are acquired.

Then, we try to collect some complementary data from contractors and owners. After that, based on architectural and structural studies (when available), possible building structural movement and the location where critical stresses will occur are investigated.

In addition, destructive tests of uniaxial tensile adhesion (pull-off) are conducted. The Brazilian standard for this test (NBR 13755/96) requires securing a 100 mm x 100 mm squared metal piece to the surface to be tested with a two component epoxy resin adhesive, isolating the cladding by sawing around the metal piece until below the under evaluation interface, attaching the metal piece to a pull tester and application of a force normal to the surface until failure has been induced. Attention must be paid to the plane of rupture: failure may occur at an adhesive interface, or cohesively within a material such as the substrate or the cladding. Based on these results, more data about adhesive mortar features, non- respect to thin-set mortar open time during installation and mortar and substrate strength are acquired. Ceramic pieces moisture expansion is also evaluated. Tile past expansion (increase on physical dimensions of ceramic tile since its cooling in the kiln until the moment of the test) and potential expansion (prediction of the expansion that the tile will undergo in its lifetime) are estimated through NBR 13818/97 procedures. This irreversible (under natural conditions) expansion of ceramic tiles can be relatively large introducing high level of stress in the cladding.

Considering that delamination and bond failure are the number one concerning and fear of owners, architects, engineers, and construction contractors the causes of these defects were also evaluated.

3. RESULTS AND DISCUSSION

The 44 buildings under evaluation were located in several cities in Brazil. Most of them were placed in Belo Horizonte (30), and the others were scattered in others cities around the country (Fortaleza, Brasília, São Paulo, Recife). These buildings were built from 1986 to 2000 and for eighteen of them it was not possible to establish the age. Pathologies were observed in buildings with different number of floors (from 3 to 25). Only two buildings had load bearing walls and the others presented concrete structural frame with clay brick or concrete block masonry.

In these 44 building it was collected 89 different samples of ceramic tiles. The ceramic tiles involved in pathologies were supplied by several manufacturers (Figure 2) from Brazil with predominant size of 10 cm x 10 cm (Figure 3). They were formed by pressing (Figure 4) and their surfaces were glazed (Figure 5). The back side of most ceramic tiles had a dovetail configuration (Figure 6).

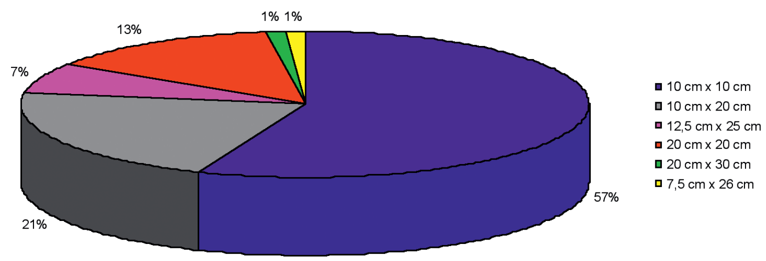


Figure 2 – Ceramic tile sizes in the buildings under evaluation.

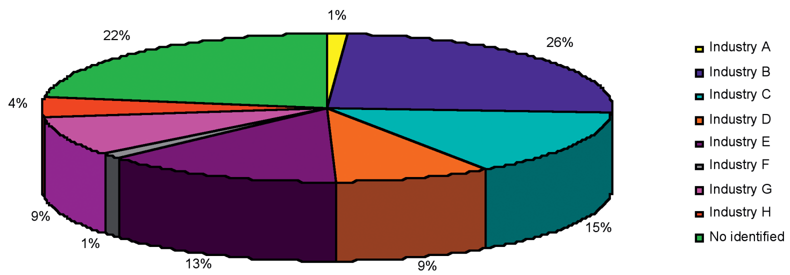


Figure 3 – Distribution of ceramic tile manufacturers involved in pathologies.

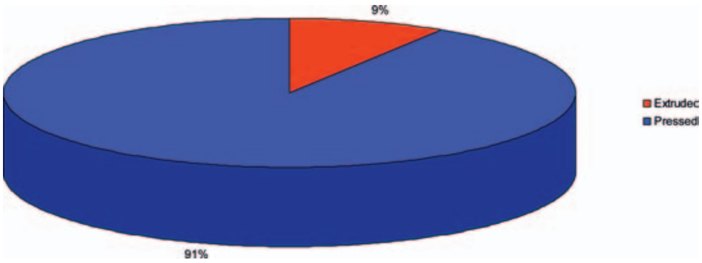


Figure 4 – Forming process of ceramic tiles under evaluation.

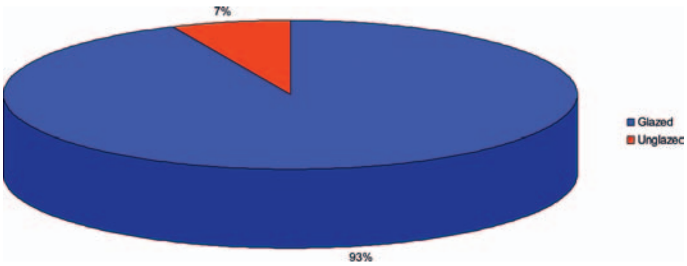


Figure 5 – Surface finishing of ceramic tiles.

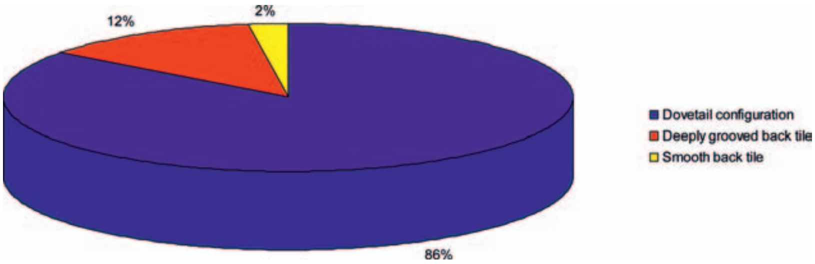


Figure 6 – Configuration of back side of ceramic tiles.

In all the buildings the cladding was direct adhered using predominantly the thin bed method of installation (Figure 7). Considering that Brazilian standards about thin bed mortars specification were published in 1998 and that the buildings under evaluation were constructed between 1986 and 2000, only in few cases we could identify the product type which several times was not appropriated for application in facades. Table 1 summarizes the types and applications of thin bed mortars as set out in Brazilian standard NBR 14081/98. Also it is important to remind that the thin bed mortar is produced since 1964 in Brazil and than used for more than 30 years without standardization.

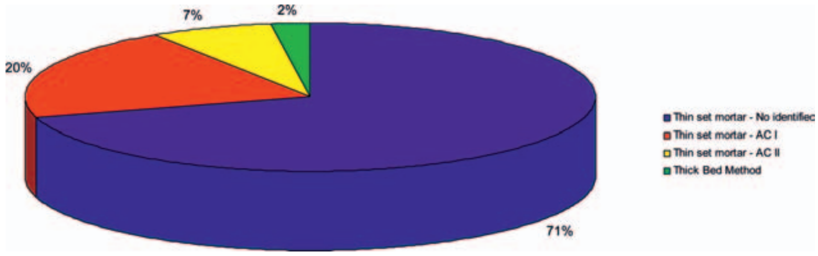


Figure 7. Installation method and type of thin-set mortar according NBR 14081.

PROPERTY	TEST METHOD	UNIT	TYPE			
			AC I	AC II	AC III	AC III-E
Open time	NBR 14083	min	≥ 15	≥ 20	≥ 20	≥ 30
Tensile Pull Strength Test	NBR 14084 (laboratory environment cure)	MPa	≥ 0.5	≥ 0.5	≥ 1.0	≥ 1.0
	NBR 14084 (under water cure)	MPa	≥ 0.5	≥ 0.5	≥ 1.0	≥ 1.0
	NBR 14084 (high temperature cure)	MPa	-	≥ 0.5	≥ 1.0	≥ 1.0
Use			Interior environ-ment	Facades, floors in public areas, light machinery	High resistance to shear stresses	High re-sistance to shear stres-ses with extended open time

Table 1. Types, uses and requirements of thin bed mortars according NBR 14081.

In less than 10% of the buildings, the width of joints between tiles was narrower than the minimum recommended width of 5 mm (Figure 8) and in all the cases they were filled with based Portland cement materials. Horizontal movement joint was observed in only 3 out of 44 evaluated facades while vertical movement joints and movement joints at existing concrete structural joints and at changes of planes or between dissimilar materials were not found (Figure 9). It is interesting to note that six buildings were built after the publication of the standard that outlines movement joints requirements (NBR 13755/96) and only one adopted this type of joint.

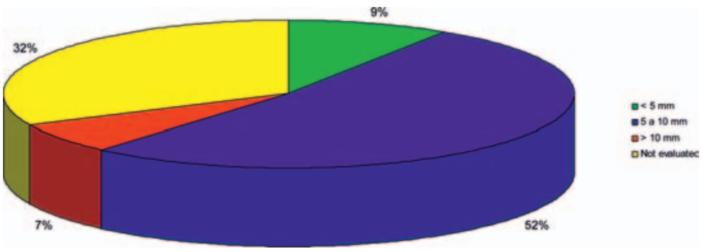


Figure 8. Statistics of grout joints width.

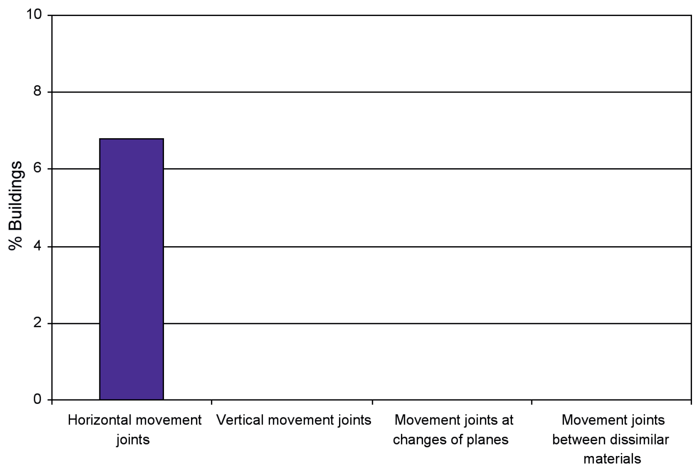


Figure 9. Graph showing the number of buildings that adopted movement joints.

The major pathologies observed at the buildings are summarized in Table 2 for aesthetics anomalies and in Table 3 for functional anomalies. Aesthetics defects affect the appearance of the facade but do not typically affect the safety while functional defects affect both appearance and human safety, as well as the integrity of other components of building. Figure 10 shows a graphic which includes all the pathologies observed in the buildings.

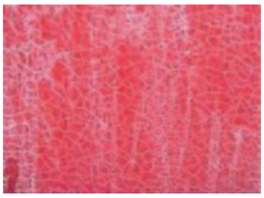
Pathology	Figure	%Buildings
Crazing of glaze		38%
Efflorescence		25%
Staining of grout material		23%
Cracking and missing spots in grout		36%
Water repellent coating staining		100%

Table 2. Summary of major aesthetics pathologies.

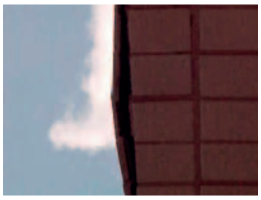
PATHOLOGY	FIGURE	% BUILDINGS
Loss of bond (tap testing)		73%
Buckling		82%
Detachment		96%
Movement cracks		25%
Failure of movement joints		100%

Table 3. Summary of major functional pathologies.

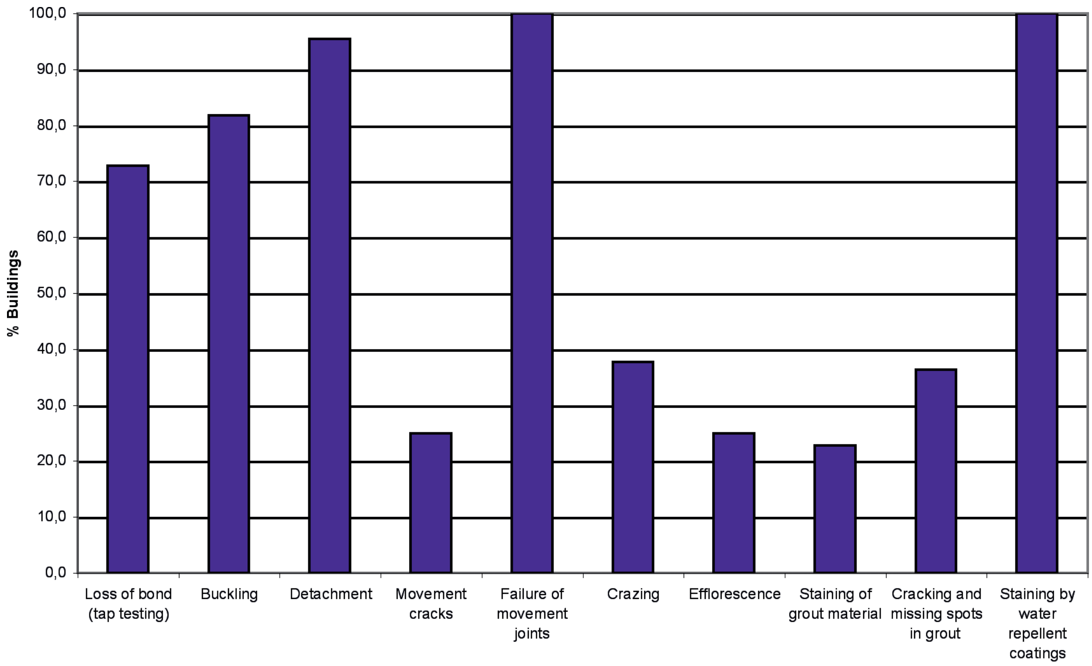


Figure 10. Summary of all observed pathologies.

Considering the causes of these pathologies, the development of hairline cracks in the glazed tile surface, also known as crazing, occurs if the thermal expansion of the glaze varies significantly from that of the ceramic body. Also, a large moisture expansion of ceramic tile can introduce stresses higher than the resistance of the glaze resulting in these fine cracks.

Efflorescence is a type of staining which consists of a white crystalline deposit. Efflorescence occurs from three simultaneous conditions: presence of soluble salts, presence of water and transporting force. Efflorescence starts as a salt which is dissolved by water. The salt solution is then transported by gravity or capillary action to a surface exposed to air where the solution evaporates and leaves behind the crystalline deposit. There are numerous sources of soluble salts in a cladding system and substrate (concrete, concrete and clay masonry units, mortars) and the control of efflorecences is a consequence of proper design, construction and maintenance of the exterior wall system to avoid water penetration.

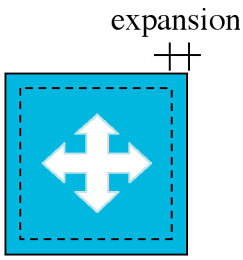
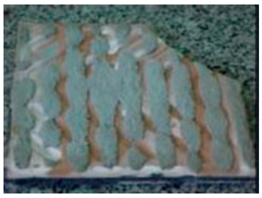
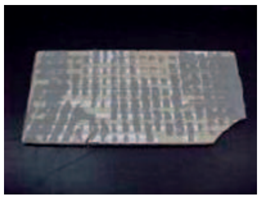
Staining of grout material is caused by several factors: water exposure and infiltration, solar exposure, biological growth, atmospheric pollution and efflorescence. Partial filling of grout joints or joints with missing spots are due unskilled installer or improperly designed joints (narrow or deep ones). Cracking of grout materials is a result of improper application, poor quality grout, improper selection of materials or mix design, drying and wetting cycles and significant overstress.

Water repellent coatings, commonly specified as a temporary solution for some facade pathologies, promote a general staining on the facade. This type of material increases the roughness of the ceramic tile surface contributing to atmospheric pollution accumulation. This problem is more evident when the coating is used only in some facade critical spots and not over the entire exterior building wall.

Functional pathologies such as lack of adhesion, bond failure, buckling and detachment of pieces or parts of cladding (delamination) have a multiplicity of possible factors of influence, most of then acting simultaneously, which require consideration and evaluation in each particular case. The main causes observed in the buildings under evaluation are listed in Table 4.

Ceramic tile moisture expansion contributes for pathologies due to the direct adhered system. As the tiles are fixed to the substrate, each differential movement will be constrained causing high build-up of stresses. Large values of moisture expansion (usually limited to 6 mm/m) can result in stresses higher than the bonding strength between different materials promoting bond failure. The presence of a coating of a release agent (engobe), which prevents fusion of the tile to the kiln roller surface, decreases the adhesive bond between the tile and the thin set mortar because it acts as barrier reducing the interfacial contact. Warpage of tiles also reduce the effective area of adhesive contact mostly due the thin thickness of adhesive layer.

Poor installation practices are easily identified by incomplete contact coverage of the back surface. This situation could be a consequence of exceed open time, improper installation, only pressing or beating the ceramic tile into the protruding ridges of the adhesive without moving the tiles perpendicular to the ridges, and not applying a layer of adhesive to tiles back (back-buttering) when they have large sizes or deeply grooved backs. In almost all the buildings under evaluation, remaining adhesive ridges could be observed after the detachment. Average contact coverage of 41 % was measured. This low level of adhesive coverage must be increased (at least 90%) if distress to installed tilling is to be reduced.

CAUSES OF BOND FAILURE, BUCKLING AND DETACHMENTS		FIGURE	% BUILDINGS
Ceramic tile	Moisture expansion above 0.6 mm/m		41%
Ceramic tile	Engobe		41%
Ceramic tile	Warpage		2%
Improper working	Low coverage		95%
Improper working	Absence of back-buttering for tiles deeply grooved		100%
Improper working	Exceeded open time		95%

Improper facade design	Absence of movement joints		98%
	Absence of movement joints between dissimilar materials		100%
	Absence of movement joints at changes of plane		100%
	Absence of study of building movements		100%
Thin set mortar	Improper selection	-	90%
	Improper amount of admixtures	-	2%
Render mortar	Lack of superficial cohesion and cracking		27%

Table 4. Causes of bond failure, buckling and detachment of ceramic pieces in the 44 buildings.

The improper facades design can be summarized by the absence of movement joints. Movement joints are the primary means of controlling stresses induced by building movement (thermal and moisture movements, shrinkage, structural movements, vibrations) allowing stress relief.

In regard to the polymeric mortar used as adhesive, the samples obtained at building site are rarely evaluated regarding to cement content and proper identification and quantification of admixtures. They are only indirectly assessed through pull-off tests whose results are a consequence of several factors mostly related to workmanship. Besides, in the same building we could obtain values from 0.0 to 0.5 MPa. Only in one building was the bond failure observed during the tiles installation and the mortar was evaluated. The cause was identified as lack of water retention admixture.

It was also observed improper selection of adhesive mortar. In some buildings we were informed that the selected mortar belonged to type AC I, not recommended for facades. Besides, some thin-set adhesive mortars identified as type AC II, and appropriate for facades when tiles present water absorption between 3% and 10%, did not meet the requirements of this type of mortar according NBR 14081/98 even three years after standard publication.

Failures at the mortar levelling render were detected when a thin superficial layer presented low cohesion with the detachment occurring in the plane between cohesive mortar and non-cohesive mortar surface. This lack of resistance at surface is attributed to two contradictory aspects. The first is associated with a high superficial loss of water from mortar not allowing completed hydration of its surface. On the other hand, the excess of water in this area, for example as a consequence of the work to provide a smooth and even surface for the cladding installation, improve the water:cement ratio in the surface reducing its resistance.

Other interesting information about bond failures is related to the location within the cladding system where the failure occurs. The graph in Figure 11 indicates that in 84% of evaluated buildings, in which was possible to identify the plane of rupture (32 of 44), it was observed a adhesive failure at the interface between cladding and polymer modified mortar, followed by 47% of cohesive rupture at adhesive mortar. In some cases, two or more planes of rupture were verified at the same building. These values are expected considering that several papers that reported the behaviour of ceramic tile coverings obtain higher shear stresses in tile/tile bed interface, when considering stresses caused by moisture expansion or thermal movements.

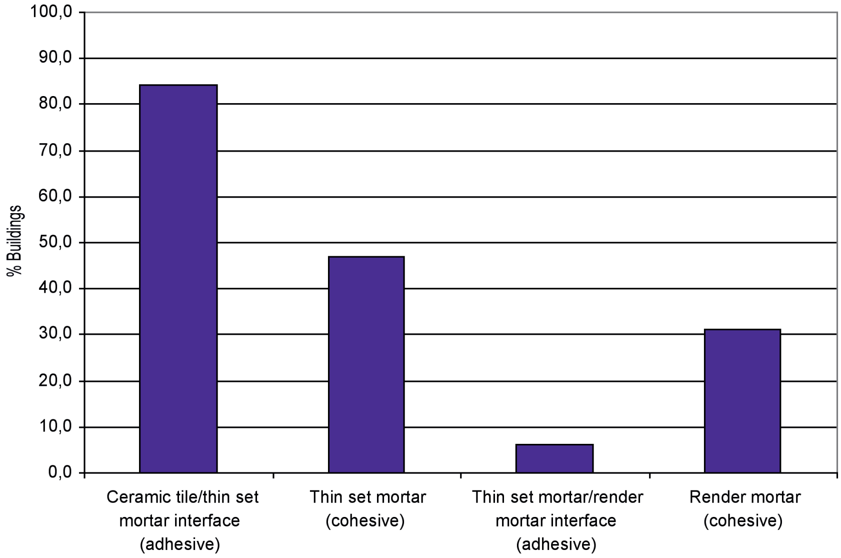


Figure 11. Rupture observed in the ceramics tiles under evaluation.

Regarding the other functional pathologies (Table 3), cracks caused by building movement and failure of movement joints were also verified. Most of the observed cracks have occurred due to the lack of a proper facade design that could have predicted movement joints at some locations where cracks developed. Other cracks are related improper design of back up wall, mostly in parapets and freestanding walls. With regard to failures at sealant of movement joints, it was observed cracks in the sealant surface and poor adhesion between the sealant and the tile. These products are routinely designed, specified, and installed improperly. It is not available Brazilian standard about requirements and tests methods for sealants in facades. Also, installation of sealants and accessories (foam backer rod) requires skilled labour familiar with sealant application practices (cleaning, use of prime agent, correct location of backer rod to regulate the depth of the sealant - according the width:depth ratio - and to prevent three-sided adhesion, and use of special tools to press the material to insure contact with tile edges).

4. CONCLUSIONS

In most evaluated cases, the defects were caused by a combination of several factors. It was possible to identify that the lack of standardization for ceramic tiles, mortar and cladding system, published only after 1996, have a great deal on the investigated problems. Today, after Brazilian standards publication, the minimal information about joints is available. Also the establishment of thin bed mortar types and methods of their evaluation, as well the spreading of concepts as open time and 100% back tile coverage contribute to the reduction of the observed problems. In addition to that, training, inspection during installation, and preventive maintenance have been increased around all the country. Nowadays, such problems have been reduced but new challenges are in scene. Standards for movement joints sealants, stresses and strains modelling of tilling systems, improvement of bond between mortar and tiles, ceramic tiles with bigger sizes are among the aspects that facade designers have to face.

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