THE INFLUENCE OF MOISTURE ON ADHESIVE PERFORMANCE

Flávio Leal Maranhão [1]; Angelo Just da Costa e Silva [2]; Eduvaldo Sichieri [3]

[1] University of Sao Paulo and São Judas Tadeu University, Brazil
flavio.maranhao@poli.usp.br
[2] University of Sao Paulo and Catholic University of Pernambuco, Brazil.
angelo.silva@poli.usp.br
[3] University of Sao Paulo, Brazil.
sichieri@sc.usp.br

ABSTRACT

Adhesive mortars are widely used to set porcelain stoneware tiles on buildings because their bond strength and flexibility properties increase the cladding serviceability. However, its long term performance is not well understood, mainly the polymeric matrix degradation.

This paper investigates the influence of moisture content on the flexibility and bond strength of the adhesive mortars, based on the EN 12002 and EN 1348 standard, on one adhesive mortar produced in the laboratory with a higher polymer content.

The results shows that: (i) the bond strength and transversal deformation are importantly influenced by the moisture content;(ii) saturation increases the matrix stiffness (iii) the logarithmic function best fits the correlations between moisture content and flexibility and bond strength; (iv) moisture content over 8% (a quarter of the saturation content) causes decreases over 50% in flexibility and bond strength.

1. INTRODUCTION

An external tiled wall is a complex multi-layer system, each one showing different properties and with rigid bonds. Stresses caused mainly by the environment agents such as rain, sun, wind and others on the system as a whole, and thus the system reacts in its entirety.

According to Medeiros [1], to achieve the system performances, the loads and the materials properties must be analyzed during the finishing design.

In façade, this factor is even more relevant owing to the larger dimensions of the claddings and the growing slenderness rates practiced in structures (Figure 1), added to the demands concerning the effects of climatic conditions [2], the fatigue phenomena [3], the inadequacy of the preventive maintenance activities [4] and the lack of regulatory technical standards.

All of this results in high levels of stress, which affect the finishing performance all along its service life.

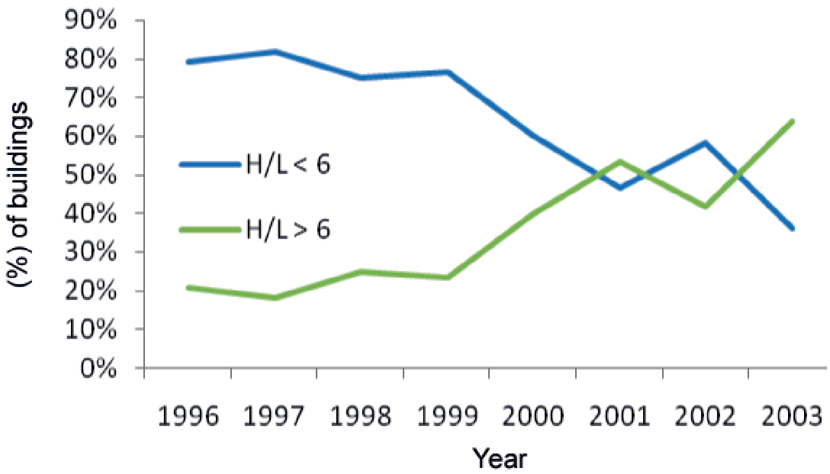

Figure 1. Variation of the slenderness rates in buildings (H /L) in the city of Recife along the years [5] . H= building height and L= building width.

The result is a high incidence of pathological problems such as cracking and detachment, in countries as Brazil [6], Portugal [3], Singapore [7] and Israel [8].

One alternative to reduce those stresses, polymer modified mortars have been used to set the ceramic tiles mainly because have lower rigidity. Moreover, those materials improve workability, water retention, mechanical properties, bond strength, flexibility and hydrophobic properties as compared to traditional mortars.

The assessment of these polymers in reducing the stiffness and conferring flexibility to the adhesive mortars has been the focus of several scientific researches [9, 10, 11, 12, 13 and 14]. In general, it can be concluded that the greater the polymer-cement ratio, the less stiff and more flexible will the adhesive mortar be.

According to Fritze [13] and Maranhão; John [14], however, these properties may present reductions over 50% of its original value when exposed to adverse conditions, such as environments in contact with water. Authors, such as Ohama [15] and Su [16], had already pointed out that water constitutes the main degradation agent in these materials.

Thus, watertightness in external ceramic finishing along their service life, besides being important issues *per se*, present great potential for changing the adhesive mortars properties.

This effect gets even more worrying, as discussed by Fioritto [17]; along time, the action of water on the ceramic linings is responsible for the emergence of compressive stresses on the plate and, specially, tensile stress on the adhesive mortar due to the different coefficients of hygroscopic expansion of these components (Figure 2). Thus, the loss of important properties, such as flexibility and adherence, studied in this research, occurs exactly when the system presents an addition to its demands.

Investigating the action of water on the mortars with polymer admixtures, Jenni et. al. [18] classified the effect into two categories: (i) **reversible** – linked to the swelling and softening of the polymer film when in contact with water, with consequences on the flexibility, on the adherence strength and on part of the expansion and contraction movements; and (ii) **irreversible** – linked to the late hydration effects of the cement with the ensuing alteration of the pore distribution.

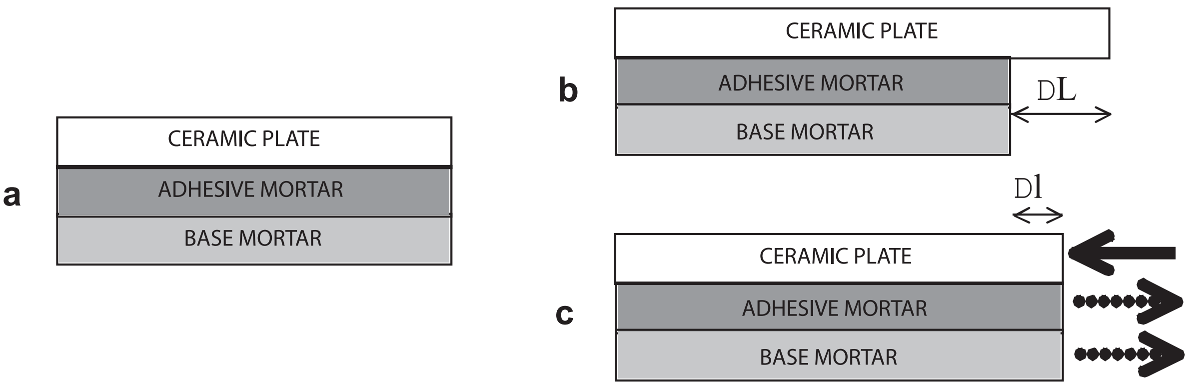

Figure 2. Diagram of acting stresses on the system due to the action of water on the ceramic Tilings (a – dry condition; b – plate water saturation (free layers – hypothetical); c – real behaviour owing to solidarity between layers).

Another point made by the author was that the intensity of the degradation of water on the polymer film is dependent on the kind of polymer used for its dispersion, stressing that the saturated cement water positively contributed to the resistance of the polymer film, when compared to the de-ionized water and with a synthetic solution that simulates cement water. The VeoVa and Acrylic polymers are more resistant compared with the acrylic and the EVA styrene. The cellulose PVA and Ether were classified as soluble.

Silva et. al. [19] synthesized the hypotheses that explain the action of water for the EVA-based mortars in the following points:

- Swelling of the PVA protective membrane with consequent softening and reduction of the mechanical resistance. In the same article, the authors did not find any proof of the occurrence of this phenomenon;
- Existence of water-sensitive products such as calcium acetate and other organometallic products, as a consequence of the chemical interaction between the PVA and the hydrate compounds in cement;
- increase in the amount of pores in the 10-50nm range, which are more sensitive to the superficial stress of the aqueous phase.

Contrary to the consensus of the damaging effect of water on the mortar properties, no agreement is found on the performance requirement of adhesive mortars when in service conditions. Authors such as [20 and 21] advocate the thesis that there is an increase in the compressive strength, tensile flexure and adherence of these mortars, based on results of natural aging essays for up to ten years; whereas Sá [22] measured reductions above 50% in the adherence strength to the ceramic plates when specimens were subjected to artificial aging cycles in laboratory scale.

Seeking to advance the points that may influence different results, this work aims to investigate the influence of moisture content on the flexibility and bond strength of one adhesive mortar.

2. MATERIALS AND METHODS

This research was developed in laboratory field.

The assessment consisted in producing the specimens, storing them in high relative humidity chamber for 48 hours followed by 26 days of exposure to non-controlled laboratory conditions with temperatures varying from 25 $\pm$ 5°C and humidity 60-70% until they were 28 days old. After that, the specimens were soaked in water for about ten days and then simultaneously removed from it and stored in piles, in laboratory ambient for 25 days. Tests were conducted along this period. After each one, cores were taken from the specimens and weighed, providing the moist mass value and then lain in ventilated oven at 100°C until the mass was constant, when they were again weighed, providing the dry-mass value. With the dry and moist mass values, it was possible to determine the moist content of the specimens the moment the essays were carried out.

2.1. MORTAR

The mortar used was especially produced for this experiment and does not mean to reproduce any type of commercially used composition. For this reason, the authors used higher polymer contents then the ones usually mentioned in the references. The mortar was composed with type composite cement (around 30% of bfs), limestone, AVE polymer type Vinapás 5010® with a 20% content in relation to the total weight of dry materials, and cellulose polymer Culminal 4051® in 1% proportion, also related to the total weight of dry materials.

According to Fritze [13] this polymer content is suitable to highly flexible tile adhesives.

2.2. FLEXIBILITY

The preparation of the specimen and the test procedures followed the directives of the standard EN 12002 [23], which are specific for assessing the adhesive mortars flexibility and already have a large amount of published data. Only the length of the upper support was modified, which was reduced from 97 cm to 2.0 cm (Figure 3) for the latter has been in use by the researches and for minimizing the variation of contact surface between the support and the specimen for large deformation cases.

For the tests, an Instron Universal Machine with a load cell unit of 1KN was used. The transversal deformation and ultimate load were measured.

Figure 3. Configuration of the test using the experimental programme for measuring flexibility.

2.3. BOND STRENGTH

The bond strength procedures were based on NBR 14084 [24], using direct pull-out test with a load cell unit of 5,0kN.

The ceramic tiles used in the experiments were porcelain stoneware with 0.1% water absorption and measuring 50mm x 50mm. The mortar was applied on a standard concrete substrate using a 6mm x 6 mm trowel and after 5 minutes, the tiles were positioned and pressed with a 2.0kg dead load for 30s.

For each substrate, ten specimens were used, totalizing forty results.

3. RESULTS AND DISCUSSION

Figure 4 shows the transversal deformation results in three important moments: before immersion (dry), saturated (wet) and after drying (25 days).

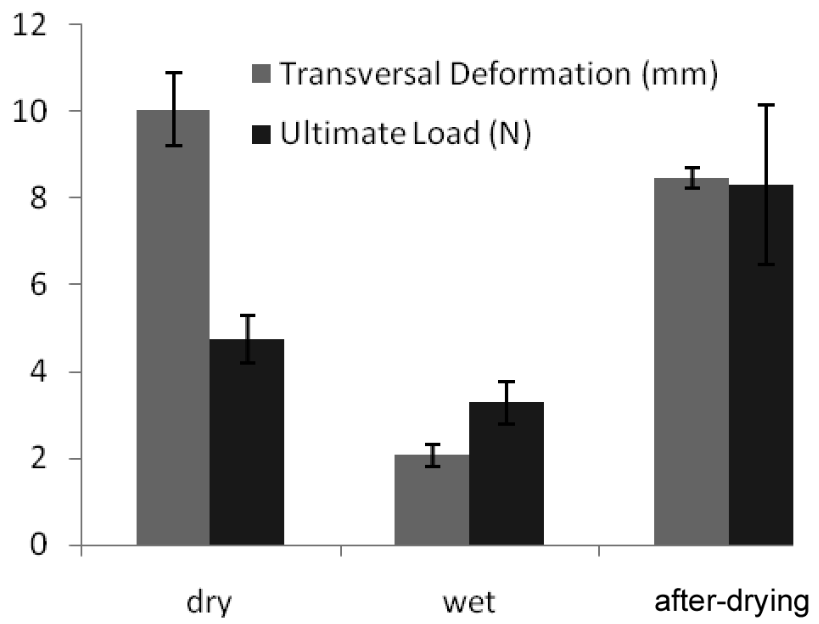

Figure 4. Average results in the transversal deformation test.

The results clearly show that the immersion in water causes important reduction in the transversal deformation and ultimate load. Moreover, during dry process the ultimate load shows an important increase (70% higher than dry) while the transversal deformation did not reach the initial value, reduction around 15%.

Fritze [13] using similar storage condition noticed that saturation can cause important transversal deformation reductions.

Figure 5 shows all results obtained during the drying process.

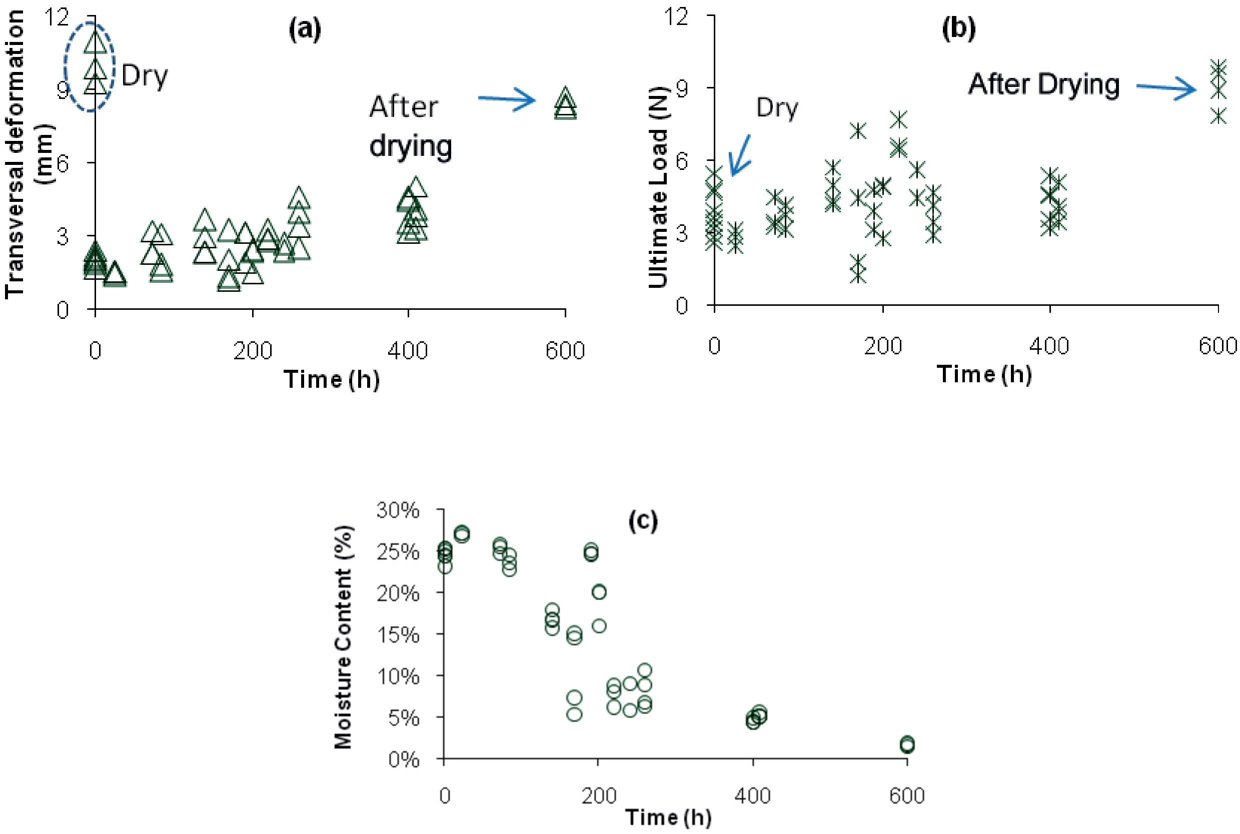

Figure 5. Transversal deformation test results. (a) transversal deformation x time, (b) ultimate load x time and (c) moisture content x time.

It clearly shows that, during drying (twenty-five days), the moisture content decreases gradually, while the ultimate load and the transversal deformation increases.

For the transversal deformation, only after 72 hours after immersion, the specimens show a deformation higher than 2,5mm, which is established by EN 12002 as the minimum for the flexible mortar (S1). For the ultimate load, a large dispersion was observed, despite the continuous increase.

It is important to note that, at the same time, a large variation in the moisture content results was observed as a consequence of differences in the surface exposition by stacking storage used.

The large time required to dry this mortar is a consequence of the cellulose polymer content that is higher than usually used.

The decrease in transversal deformation is caused by swelling and softening in the polymer matrix [18]. The increases in the ultimate load is the cement hydration that changes the mortar porous system [19].

Figure 6 shows the transversal deformation and ultimate load compared with the specimen's moisture content.

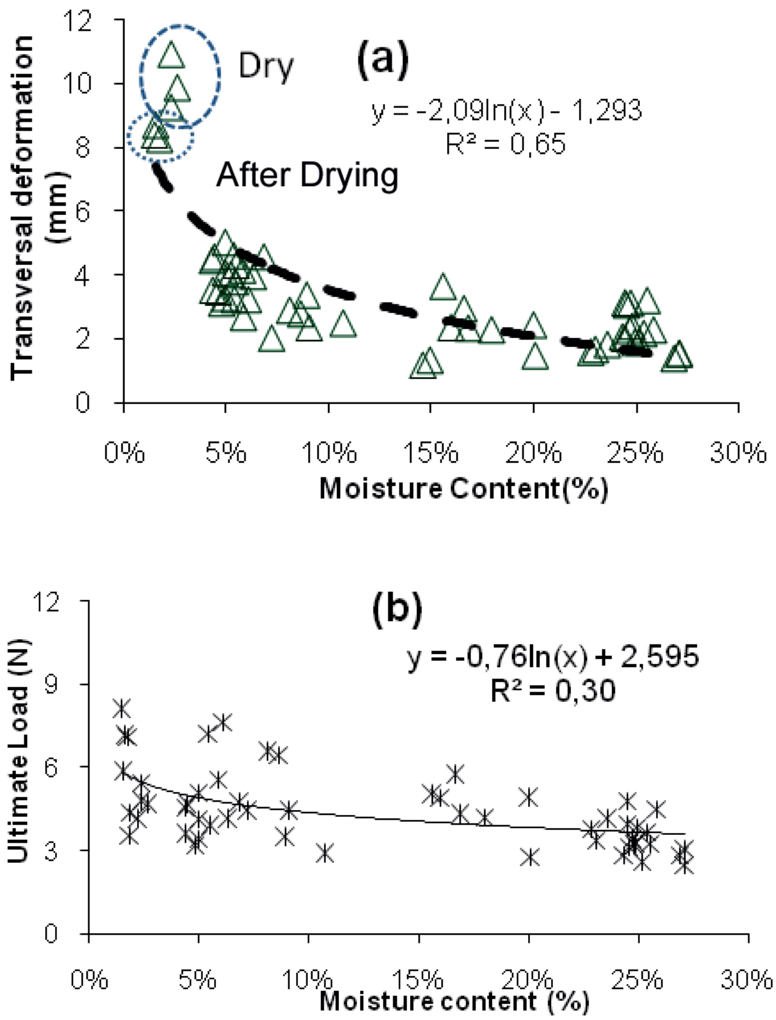

Figure 6. Results for the transversal deformation test. (a) Flexibility and (b) Ultimate load.

In this case, a clearly logarithmical correlation was observed between transversal deformation and moisture content.

The "dry" and "after drying" specimens moisture content were similar (around 2%), and values higher than 5% cause important reduction in transversal deformation.

The ultimate load did not show a good correlation with moisture content. An explanation for this behaviour could be a low accuracy in the load cell unit used (1000N) for values below 10N .

Figure 7 shows the bond strength result.

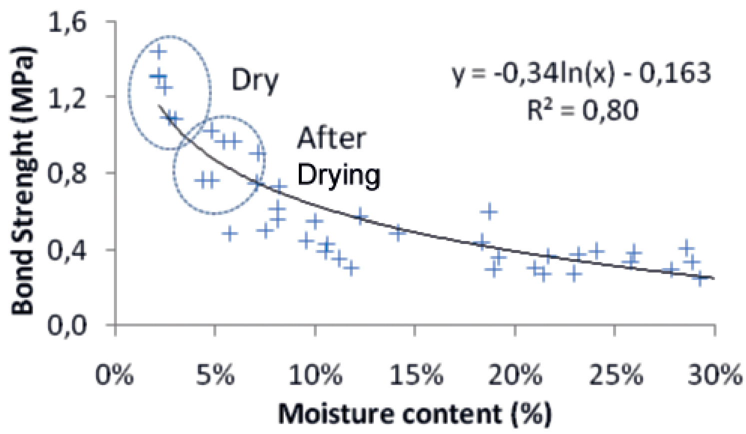

Figure 7. Bond Strength x Moisture Content.

The figure shows an important reduction in the bond strength when the moisture content increases. In this case, the "dry" specimens show a moisture content similar as observed in the transversal deformation test (around 2%) while the "after dry" did not (ranging from 5% to 7%). This behaviour is probably for a lower drying kinetics by the ceramic tile protection.

Bond strength reduction by saturation is well documented [11 and 25]. In this case, to reach 0.5N/mm^{2}of bond strength the total saturation is not necessary. Values higher than 15% are enough.

Similar as observed in the transversal deformation test, the logarithmical correlation was the best to fit the results.

Figure 8 shows the bond strength and transversal deformation results normalized (1.45MPa and 10.95mm for the Bond strength and transversal deformation, respectively).

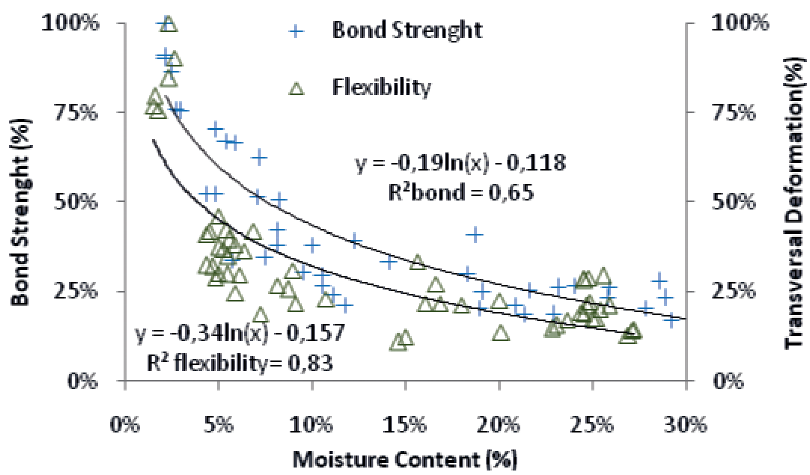

Figure 8. Normalized results for the bond strength and transversal deformation.

It is clear that both curves are similar despite different correlation indexes. For this mortar, a moisture content higher than 8% is enough to reduce the transversal deformation and bond strength more than 50%. This moisture content represents 25% of the highest value measured in this research.

4. CONCLUSION

The performance of adhesive mortar used to set porcelain stoneware tiles should be greatly influenced by several aspects, such as moisture content and temperature.

Based on those results, it is clear that the adhesive performance depends on the water tightness of the ceramic tile system, which, in practical terms, is controlled by the integrity of the grout mortar. Moreover, despite no defect, the condensation could increase the mortar moisture content.

Therefore, it can be expected that the effect of the polymer on a real façade can be reduced due to real humidity and can be the cause of cladding failures, such as detachments.

The main conclusions from the laboratory results are as follows:

I. The bond strength and transversal deformation are greatly influenced by the moisture content;

II. The bond strength shows a better correlation with the moisture content than the transversal deformation does;

III. That the water immersion increases the matrix rigidity, characterized by an ultimate load increase;

IV. The logarithmic function is the best to fit the correlations between moisture content, flexibility and bond strength;

V. Moisture content over 8% (a quarter of the saturation content) causes decreases over 50% in flexibility and bond strength.

Despite the results obtained, this work demonstrates that important properties of the adhesive mortars such as deformability and adherence strength, essential for an adequate working of the system, are quite sensitive to the presence of moisture. With this, considering the natural exposition of these mortars to wetting-drying cycles along their use on façades, it is of paramount importance to define, in the design, acceptance criteria for these products so that drop in the expected performance can be foreseen, as proved in the present study.

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