Decay of historic azulejos in Portugal: an assessment of research needs

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SUMMARY: LNEC's next quadrennial research programme is being prepared and one of the new research themes will be centred on the conservation of historic glazed ceramic tiles. Since one of the aims of this seminar is to identify research needs in the field, we present in this paper an overview of a recent investigation that included on-site observations, laboratory work, and numerical simulations. That investigation is the subject of this paper and aimed at identifying research needs and establishing research goals on major issues related to the decay mechanisms of azulejo panels, as well as paths to be pursued towards a scientifically-based approach to their conservation.

KEY-WORDS: azulejo; glaze; salt decay; decay of glazed tiles; majolica tiles

INTRODUCTION

Historic ceramic tiles, azulejos for short, are very important to Portugal, being inextricably linked with the aesthetics of its architecture for over two centuries. They are considered a valuable cultural asset and, in their heyday, a distinctive mark of Portuguese culture.

Soluble salts are referred by several authors [1, 2, 3] as a major cause of azulejo decay and, aside from human actions, are likely to be the most important cause of decay and loss of single tiles as well as of whole panels. When soluble salts crystallize inside the pores and cracks of the biscuit, the internal tensions arising from the crystallization will tend to progressively disaggregate the material and, in particular, to separate the non-porous glaze from the biscuit, promoting progressive glaze detachment. Since the colour is inlaid in the glaze, its loss entails the total loss of the decoration. Besides affecting the cohesion of the glaze/biscuit bound, salt crystallization causes or propagates cracking and alters the porosity of azulejos, influencing the circulation of water in them.

The nature of the salts does not depend on the azulejos themselves and has been identified by several authors in other cases [e.g.15]. The glaze/biscuit interface has also been studied by several authors [e.g.4] in single and double fired glazed ceramics but we are not aware of any comprehensive study of the degradation patterns at the microscopic level in azulejos. The causes for decay taking place in a particular zone of a tile and not elsewhere and the mechanics of its propagation have not yet, to the best of our knowledge, been addressed. Neither has research been carried out on ways to, as far as possible, immunize tiles against decay by preventing its onset or halting its propagation.

Besides salt crystallization, the presence of moisture may also have other harmful consequences, which may be relevant as regards the decay of azulejo panels, for instance: biological growth; chemical reactions; lixiviation; and freeze/thaw damage which we shall not address here.

We visited different monuments in Portugal, ranging from the Southern province of Alentejo to Minho, at the Northern part of the country, aiming to assess decay patterns, particularly when caused by salt crystallization. Some of the observations carried out on these monuments are presented below. Having secured several samples, we conducted also a laboratory study whose main aim was to identify potential weaknesses in the glaze/biscuit interface. These samples were often contributed by persons willing to help conservation efforts (and to whom we are very indebted) and, therefore, their exact provenience was not always possible to identify. Indeed, representative sampling requires a comprehensive planning that was not executed within the framework of this preliminary study which included numerical simulations of cracking and crack propagation, as well as microscopic validation observations. Global analysis of the data obtained allowed establishing several explanatory hypotheses that we shall verify within a future research program at LNEC, of which more later.

SITE OBSERVATIONS

A first impression one gets from on-site inspections is that azulejo panels are very durable. Indeed, only a few cases show widespread decay. However, it must be borne in mind that panels made from tiles that were, so to say, factory-flawed, must have decayed away and been replaced long ago, particularly when exposed to aggressive conditions. Thus, what we find today are those that are either in a dry environment, or else have proved themselves in a real-life long-term durability test much beyond our laboratory simulations. However, when conditions change and moisture intrudes, azulejo panels that seemed durable enough may actually decay fast, apparently even in the absence of salts, as happened at the Oporto Cathedral (figure 1) when a cover that once protected the upper level of the cloister was removed, exposing the azulejo panels to conditions from which they had previously been protected.

A typical example of the results of an unfavourable external exposure may be seen at Casa dos Patudos in Alpiarça. Figure 2 shows peeling of the paint above one of its external azulejo panels. This is a pattern characteristic of capillary rise from the ground, leading to salt crystallization above the panel, which is little permeable to water vapour. A closer inspection shows that some of the tiles are also affected and that their glaze is scaling off.

But interior panels may be equally at risk, particularly when water with dissolved salts ascends in the wall. Figure 3 illustrates a case at the Old University of Coimbra. Again, the paint is peeling above the azulejo panel (3a) but in this case the glaze of the tiles is cracked, offering an alternative way out for the moisture, and the fissures of each azulejo are highlighted by efflorescence (3b).

Figure 1- Decaying panel in a now exposed area (Oporto Cathedral, upper cloister gallery)

Figure 2- Salt crystallization above a street azulejo panel at Casa dos Patudos
(photo by Manuel Anastácio, Wikimedia)

Figure 3a- Interior azulejo panel (Coimbra)

Figure 3b- Efflorescence at the same panel

Figure 4- Generalized decay at the wet zone of an interior panel (Church of Jesus, Setubal)

A case that illustrates plainly the full consequences of moisture in walls is to be seen at the Church of the Convent of Jesus in Setubal, Portugal. Figure 4 shows one of the XVIII century panels inside the Church. The wall is moist at the top of the panel and paint peeling is again apparent in some areas suggesting that salt crystallization is active. The photo shows that decay propagates from the edges and corners of the affected tiles. However, it does not attack all tiles equally and, in fact, some individual azulejos are free from decay, at least at a macroscopic level. In other cases, decay affects only three edges of an individual tile, but not the fourth, suggesting that it starts at weak points that may be absent from some tile edges. Finally it was noticed, in this and in other cases, that tiles are often affected by the pair whenever decay progressed from edges (figure 5), or by three or foursome when decay progressed from corners (figure 6).

Figure 5- Decay progressing from edges

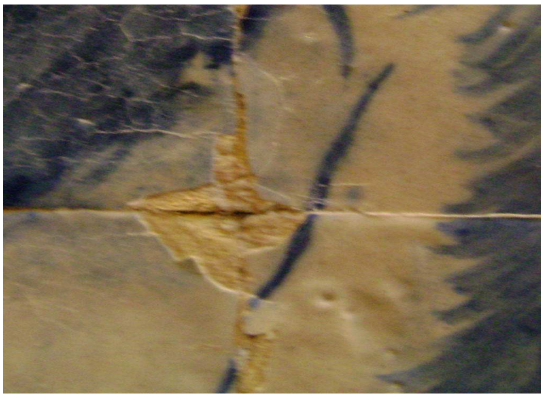

Figure 6- Decay progressing from corners

MICROSCOPIC OBSERVATIONS AND NUMERICAL SIMULATIONS

Microscopic observations on azulejos may reveal interesting features. Figures 7 and 8 show scanning electron microscope (SEM) images of slightly polished sections through the glazing and adjoining biscuit of two different azulejos. The first shows a sound glaze/biscuit interface while in the second the glaze is scaling off on a front parallel to one of the edges, as seen onsite in salt-laden tiles.

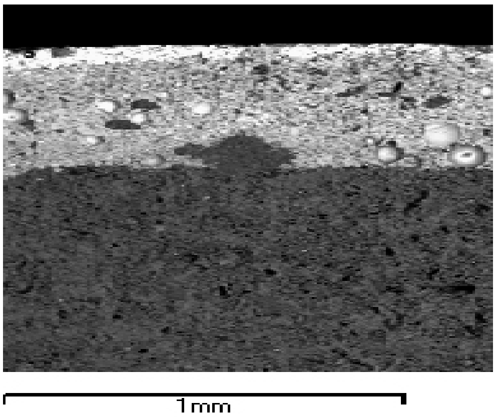

Figure 7- SEM image of a sound azulejo glaze/biscuit interface

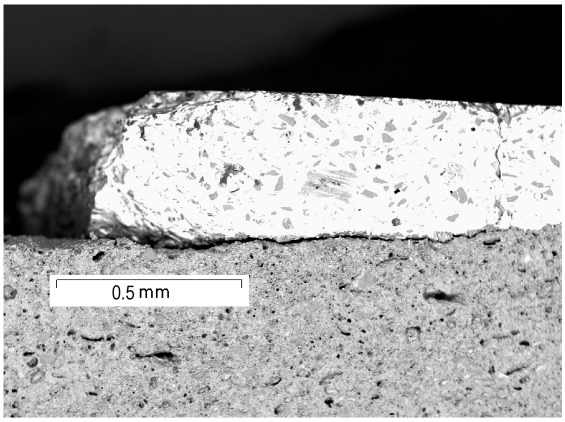

Figure 8- Backscatter SEM image of glaze detachment in progress- a fringe of glazing is about to fall off

Figures 9 and 10 depict, through optical and SEM images, examples of defective tiles in which extensive cracks run under the glaze which is thus locally detached from the biscuit.

The widespread glaze detachment seen in the images is a very worrying defect because it may potentially lead to the catastrophic loss of large areas of glaze. We did not find any causal relation with salt crystallization, but such delaminations are well-known in new tiles as defects that occur when the tile cools after the firing of the glaze. This is a case where numerical models may help to better understand the complex physical processes involved, and so we decided to apply them by modelling the internal stresses that develop during the cooling process.

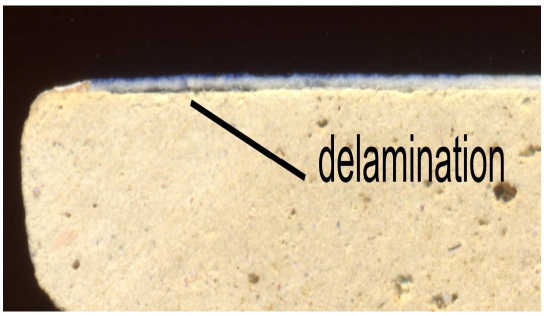

Figure 9- Extensive glaze detachment

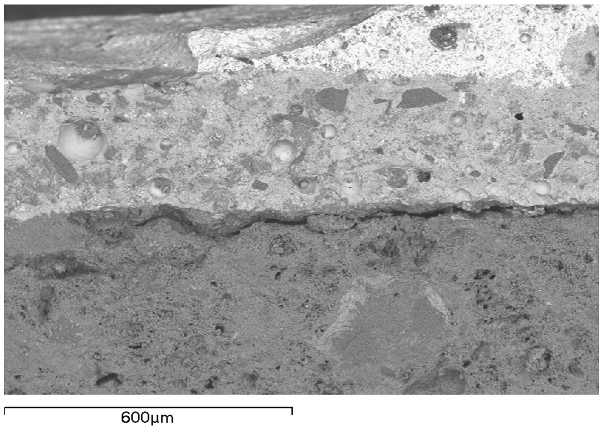

Figure 10- SEM image of glaze detachment

When the tile cools, if the thermal expansion coefficients are not finely tuned, the glaze top may contract substantially more or substantially less than the biscuit. In the first case, the clay body exerts through the interface a homogeneous traction on the glaze. Glass cannot respond elastically and thus may crack. The fissures propagate sideways, until a crack meets another at an app 90º angle, and vertically until the tension is relieved [5]. This situation leads to crazing, the formation of a cracking pattern in the glaze (the so-called craquelé) which resembles drying mud. Visually, the pattern seems formed by odd trapezoidal polygons with similar dimensions.

We have simulated azulejo crazing with a numerical model based on a Delft lattice [13] on a Matlab environment. Figure 11 illustrates two steps of the evolving process when the bound between the glaze and the biscuit is considerably stronger than the cohesion of the biscuit itself. In this case the larger vertical cracks may propagate more or less extensively into the biscuit.

When, however, the bound between glaze and biscuit is of the same magnitude or lower than the cohesion of the biscuit, the cracking will follow the path of less resistance under the glaze and detach it locally from the biscuit (figure 12).

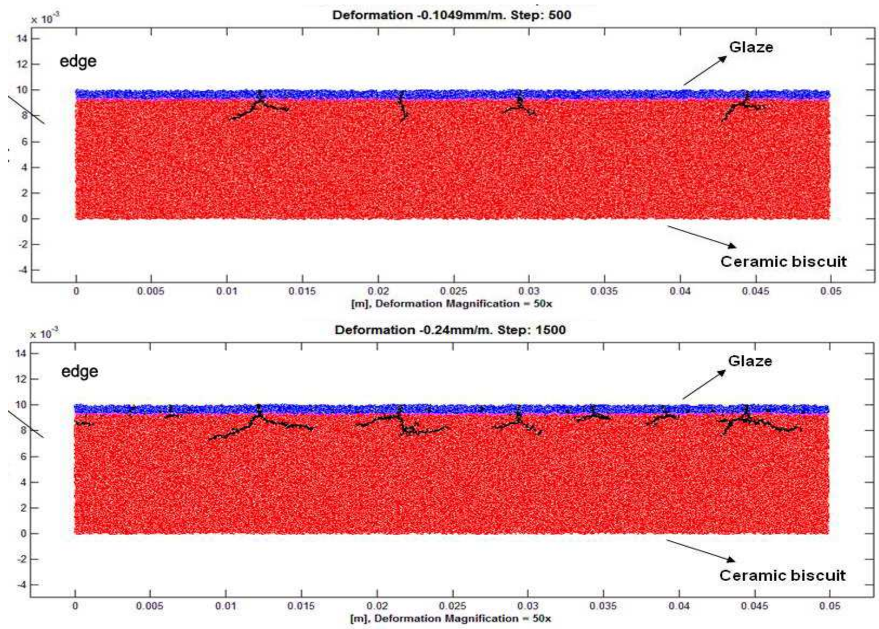

Figure 11- Two steps of the graphic result of a numerical model of cooling tile crazing with a strong glaze/biscuit bound

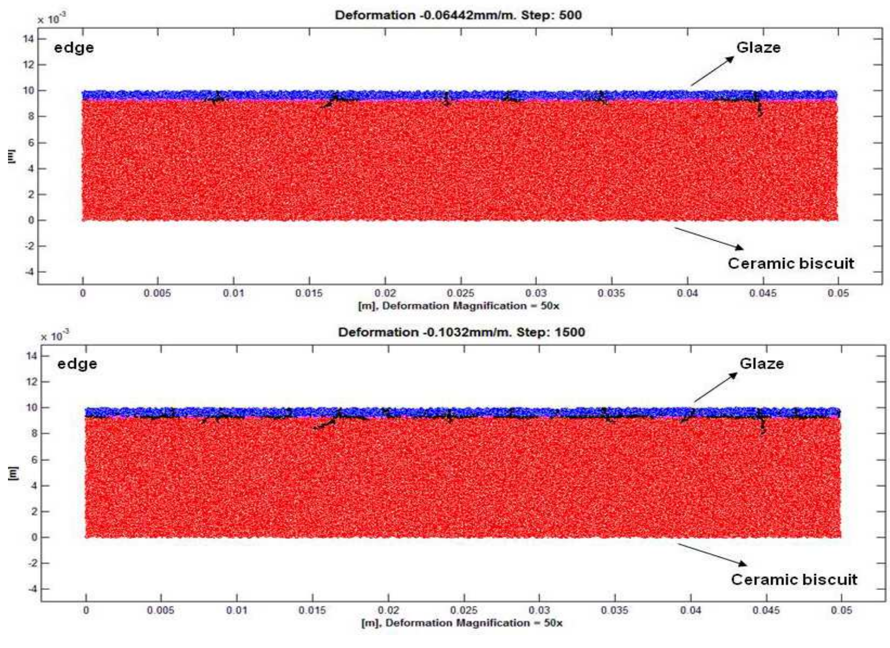

Figure 12- Two steps of the graphic result of a numerical model of cooling tile crazing with a relatively weak glaze/biscuit bound

Figure 13- Section through a crazing crack propagating into the biscuit

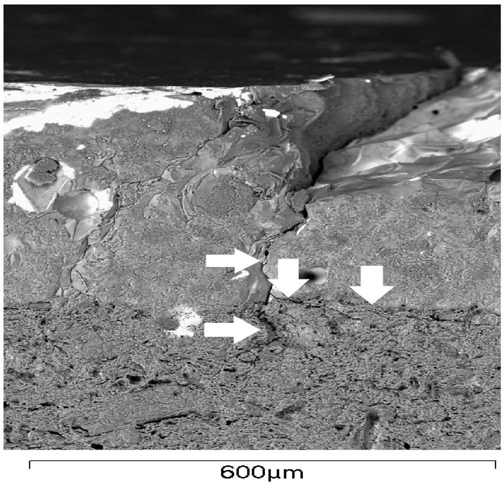

Figure 14- SEM image of a crazing crack propagating mostly into the glaze interface

Cracking patterns that resemble those obtained by numerical simulation (figures 11 and 12) were indeed found in actual azulejos. Figure 13 shows a XVII century azulejo where the glaze cracking propagated into the biscuit, while fig. 14 shows a case of the same vintage where the crazing crack propagated mostly in the glaze/biscuit interface. In extreme cases of this last instance, the glaze will form “islands” that are only bound to the biscuit at their central part, and eventually fall-off in patches.

A less known but potentially very noxious defect is shivering, which stems from the opposite situation: during the cooling phase, the biscuit contracts considerably more than the glaze. Due to the resulting compression tensions, the glaze may suffer small cracks or detach from the biscuit. Characteristically, shivering causes glaze nicks at the edges and, when severe, may possibly result in extensive detachment of the glaze. The results of a numerical simulation (figure 15) show that, due to the arising stresses, the glaze may separate locally from the substrate and break, cause vertical cracking of the clay biscuit or, indeed, even suffer extensive detachment.

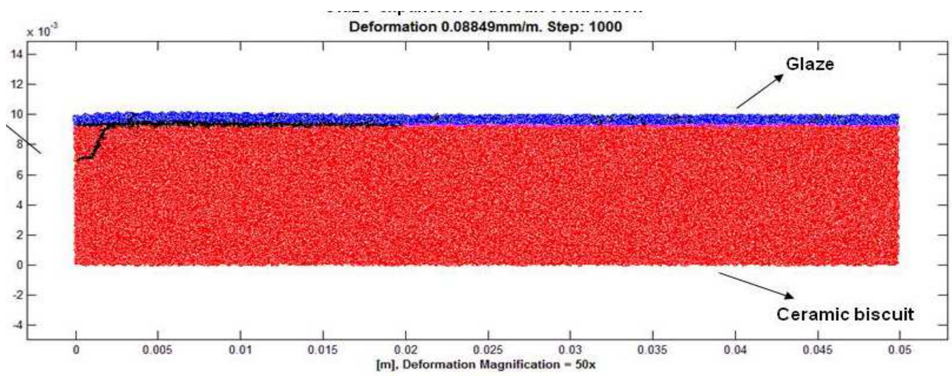

Figure 15- One step of the graphic result of a numerical model of cooling tile shivering

The damage patterns depicted in Figures 9 and 10 are consistent with, and probably correspond to cases of shivering. They are very different from the example of figure 8, where glaze detachment evolves piecewise, in advancing fringes.

CONCLUDING REMARKS AND FUTURE RESEARCH PATHS

Returning now to the decaying panel of figure 4, it is not possible, based on the available information, to state why decay started in each individual tile. As decay propagated, the original evidence was progressively erased. But even for the azulejos where decay is macroscopically beginning, a sound diagnosis would require a set method, not yet established, which takes us back to the theme of the present research needs.

From the cases known, we may hypothesize that decay always starts at a critical point: a defect, albeit microscopic, where water finds an easier penetration path into the interface beneath the glaze. Whenever the joint is, so to say, “sealed”, the decay process starts much later, accounting for the different performance of individual tiles in the same decayed panel. Indeed, as the scale is reduced, weak points will always be apparent, but some are critical in the sense that they present an immediate danger in the existing environment, while some are not.

Such points may occur e.g. because of crazing, impact or other mechanical actions. Another factor that may conceivably originate critical points in azulejos stems from hydric dilation. Portuguese tiles applied in panels are designed for surface continuity, so that the width of joints does not interfere with the image. Their sides are bevelled and, when mounted together to form a panel, their edges contact. The traditional technique, which we believe was the same still used in the first half of the XX century, called for the submersion of the tiles in buckets of water for 24 hours before applying, supposedly to expand them to their maximum dimension. After drying they would shrink slightly, therefore avoiding interference. But research has shown that a tile will not attain the maximum expansion in 24 hours and, actually, for modern tiles a span of three years has been mentioned to this effect [14]. If, after being applied, the tile is subjected to continually moist conditions, its dimensions may therefore increase beyond their initial size. If the edges of adjoining tiles come to contact, any protruding glaze will contact the glaze of a contiguous tile, impairing one or both and making of them candidates to decay. Noticing that cases are often found, as in figure 6, where four tiles are decaying because of the damage sustained from the insertion of a single small nail at their meeting point; we do not have to go very far in stating that contact damage may well account for the decay of the paired tiles seen e.g. in figure 5. Once started, decay will not stop by itself. Rather, decayed areas where the glaze is missing will provide a preferential evaporative route for moisture in walls, straining the adjoining glaze boundary with more and more salt crystallization.

Summing up our conclusions we must state that the notion that azulejos are long-lasting is not backed up by onsite inspections: their durability depends largely of their being defect-free and mounted on essentially dry walls. Tiles with manufacturing defects may have their glaze partially cracked or delaminated, thus offering easy routes for moisture propagation and, eventually, salt crystallization and decay. Numerical methods may provide a valuable simulation tool to help explain cracking patterns. Very often these patterns result from the manufacturing process and so tiles may be flawed from the onset. Other flaws may result from human action (impacts, insertion of foreign objects into the joints, etc.) or physical interference between tiles applied closely together. When subject to adverse conditions, these factors will all lead to decay, initially localized and later widespread, eventually resulting in the loss of whole panels.

Addressing now the research themes mentioned in our initial summary, a line we are pursuing at the moment is the study of the interface between glaze and biscuit to understand its characteristics, to determine its nature when sound and to detect possible weak spots. Some of its results were included in this paper. This reconnoitring work is to be pursued both onsite, where we are documenting decay patterns, and in the laboratory through microscopic examination. In the future, accelerated ageing test protocols will be proposed. Selected test items will then be subjected to aggressive environments aimed at simulating situations found in practice, which lead to decay, so as to ascertain the onset and evolution of the process. Subsequently, we intend to evaluate technologies allowing the sealing of weak spots, both based on known products [6] and on emerging ideas [7, 8]. Their effectiveness will be evaluated through a specific method that will include accelerated ageing tests.

If, because of shivering or any other similar defect, the interface between glaze and biscuit is partially detached and is subsequently penetrated by water from the back, the situation may lead to blistering and spalling, a condition in which the glaze bulges and further detaches from the substrate [9] eventually breaking off and causing an approximately circular lacuna. We have found several situations where the glaze is apparently bound to the clay but actually is extensively detached. A proposed research theme includes the mapping of the fissural systems of tiles (the use of x-ray tomography is foreseen) aiming at understanding them. The results will lead to the tentative detection onsite by non-invasive means of dangerous situations, exploring recent advances in this specific field [10], which were fostered by the need to detect delamination in modern pressure cast tiles, as well as state-of-the-art means now being experimented on frescoes [11]. Once the means of detection are set and calibrated, the tiles at risk may be identified and tagged as candidates to intervention.

Tiles where decay is predictable or is already progressing must be intervened to preclude or stop the on-going damage and consolidate the glaze in detachment, possibly with inorganic consolidants as used for silicate-based rocks [12, 15] and, if feasible, seal back the whole affected joint in a responsible and lasting manner. The exposed biscuit must also be dealt with, so as to avoid a tunnelling effect towards moisture in the walls. Studies aimed at supporting this type of restoration interventions will be made, with the objective of evaluating the effectiveness and possible collateral effects of restoration products and methods as well as their durability.

These are our plans for the near future!

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