EFFECT OF COASTAL ENVIRONMENT IN CLAY FACING BRICKS AND ROOF TILES

B. Sena da Fonseca
J.A.R. Simao
C. Galhano
CICEGe, U.N.L. – Fac. de Ciências e Tecnologia, Dep. Ciências da Terra, Caparica

Abstract:
Materials made from clay, such as bricks or roof tiles are widely used in recent buildings. Their severe exposure to salt spray, common in coastal environments could cause premature degradation which leads into functional, aesthetic, economical and safety problems.
The aim of this study is to analyze and quantify the physical and mechanical alteration caused by salt spray in modern facing bricks and roof tiles. For this purpose, one type of roof tile and two types of bricks were submitted to various stages of accelerated aging test by salt spray. Visually and binocular microscope inspection reveal visible degradation. The tests to evaluate the physical and mechanical characteristics of the bricks and tiles were made before, during and after the aging test, the results expose a general unfavorable trend in expected performance of the three types of materials. It was possible to identify the main intrinsic characteristics of the materials that have led to their degradation.

Key Words: Clay bricks, roof tiles, alteration, salt spray, accelerated ageing test

Introduction

Clay has been widely used as a raw material in constructions and buildings materials since 8000 BC (Houben & Guillawd, 1994). Roof tiles in houses coverings have been an ancient tradition and their current use allows the maintenance of the architectural tradition in many countries. On the other hand, their diverse forms, parts and accessories allowed varied aesthetic effects (Garcez, 2009). The facing bricks industry is currently the most interesting and their applications suffered a technological revolution in terms of manufacturing and material types (Parras, 1997). These bricks have a diverse range of characteristics, depending on the raw materials and manufacturing methods and procedures (Lucas, 2003). For a long time, the degradation of these and other construction materials have been a concern, largely due to lack knowledge of physical, chemical and mechanical properties of the materials in use and also to a disregard of environmental conditions where they will be implemented. This could, affect in long term, the materials correct performance and cause aesthetical, functional and security problems (Moser, 1999). It is well known that its rehabilitation, maintenance or substitution implies high financial costs.

The salt deterioration has been widely studied in recent and historic structures and in most of the cases the attack occurs due through rising dampness from soils (Ottosen *et al.*, 2007; Rorig-Dalgaard *et al.*, 2012). Another source of harmful salts is the sea spray, which is common in coastal areas in all parts of the world.

According to the Intergovernmental Panel on Climate Change (IPCC, 2001), every year are release into the atmosphere 3300Tg of small particles in salt spray form. These particles are produced due to wave breaking, by three mechanisms (Leeuw, 1999). During the wave breaking process, air bubbles are introduced in the water column and then return to the surface a bubble film is formed which separates the interior of the air exterior. When the film breaks produces small droplets. From other side, the bubble could collapse immediately after reaching the surface. Also when the wind speed is higher than 9 m/s, particles are naturally released from the sea.

The transport of these particles to onshore is a current situation and occurs through wind and turbulent sea that causes displacement of air. Sometimes the sea influence in the atmosphere is enhanced up to 20 km into the shoreline (Silva *et al.* 2007).

Therefore, it is obvious the interaction between the salt spray from sea and building materials, particularly in clay bricks and tiles. The degradation caused by this salt spray has been widely studied through short-term test in laboratory. Their effect is well known in several construction materials, e.g. in ornamental rocks (Galembeck *et al.*, 2008; Silva & Simão, 2009). Efflorescence resulting by salt deposits has been observed in old clay ceramic facades and results in harmful types of damaging like exfoliations or spalling (Kuchitsu *et al.*, 2000; Brocken & Hijland, 2004; Lubelli *et al.*, 2004). Due to severe exposure to sea spray, this type of degradation has also been found in several recent buildings. As an example, figure 1 show a photo taken in a building facade from a Portuguese coastal city (Sesimbra) a few years after its construction, where deterioration is clearly evident.

Studies in modern bricks are scarce and the physical, mechanical deterioration arising this interaction is poorly known. This work aims the study of the alterations of modern ceramic materials when subjected to a coastal environment, under the action of the salt spray. Physical, mechanical and aesthetical modifications in tiles characteristics were monitored by several laboratory tests.

Figure 1 - Aspects of clay bricks degradation due to sea spray action, Sesimbra, Portugal.

Materials and methods

For this investigation, three different kinds of commercial fired clay ceramics were used. The samples were taken from three different Portuguese manufacturing industries. A roof tile, “lusa” (RT), manufactured with a maximum firing temperature of 1035°C and two types of facing bricks, a extruded unglazed brick (EU), class AIb (EN 14411) and a extruded glazed brick (EG), class AIa (EN 14411), subjected to a firing temperature of 1230°C and 1220°C, respectively. Additionally, the granulometric study of RT and EG raw materials has been carried out by wet sieving for the fraction >0.063mm and with a SEDIGRAPH analyser the fraction <0.0063mm, the supplier of EU did not provide the respective raw material.

In the absence of a European standard for accelerated aging test for salt mist in building bricks and tiles, the EN 14147 for natural stone was followed with appropriate adjustments to the material under study. To this aging test salt spray chamber (ASCOTT S120T) was used. The salt solution contained 1 part of NaCl to 9 parts of distilled water. The spray cycles were comprised by 8 hours of active spray and 16 hours of drying at 40°C (± 2°C). The process was repeated for a total of 60 cycles. Each 10 cycles, the samples were removed from the chamber and weighed before and after 10 days of desalination by immersion in distilled water.

Every 20 cycles, the samples surface was visually inspected with a binocular microscope and the alterations registered by microphotography.

After 20, 40 and 60 cycles, six samples were used to water absorption and apparent porosity determination (EN 10545-3) and five samples were used to obtain the modulus of rupture (EN 10545-4). For the assessment of the main mineralogical composition, samples of the tiles were cut after and before the 60 cycles and submitted to x-ray diffraction.

Results and discussion

Raw Material

Figure 2 shows the granumetric analysis of the raw material corresponding to RT and EU. The analysis of the granulometric curves revealed that the average size of particles in the raw material of RT is higher than the average particle size in the EU.

The curve corresponding to the EU also reveals a smoothness slope indicating a higher range of sizes. The curve corresponding to RT has a uniform granulometry, the fraction between 30 µm and 3 µm has more than 50% of the material. In RT it is also possible to identify a 3% of particles larger than 500 µm.

The raw materials of both materials reveal the existence of a significant fraction <0.3 µm, outside the detection range of the equipment, 6.78% in RT and 26.99% in EU.

It is consensual that the raw material granulometry has a major role in the sintering process and in the overall properties of the clay ceramics (Sokolar & Swetanova, 2010). By this reason, and independently from other manufacturing parameters, with the obtained data it is possible to make a relative prediction in tiles characteristics. The suitable uniform granulometry in raw material of RT gives a good compactness which produces tiles with low porosity. However, the low average size of particles in EU raw material could contribute to smaller pores and lower percentage of porosity in terms of the total volume.

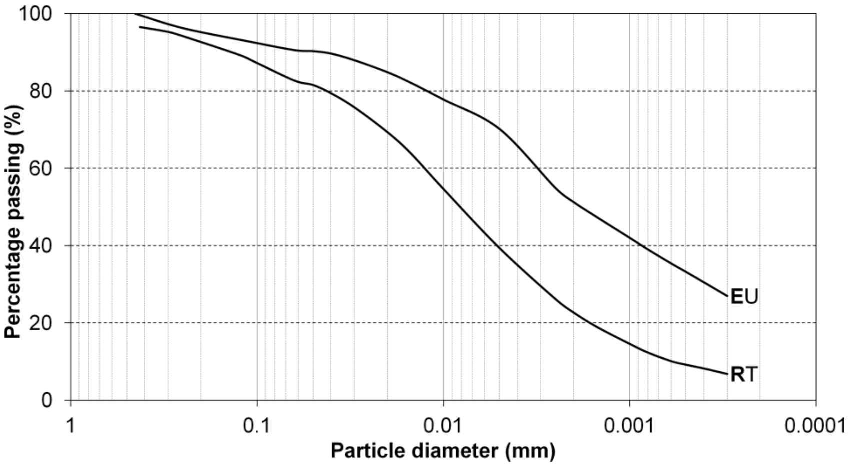

Figure 2 - Granulometric curves of raw materials.

Clay ceramics

Weight variation and visual inspection

Figure 3 and 4 represents the cumulative mass weight variations before and after samples washing, respectively. In general, it is possible to see higher values of mass variation for RT and smaller to EG. The higher or lower presence of salts within the porous structure, and the efflorescence on the surface, are reflected in the obtained mass values. This is an indication that the porosity must be greater in RT, smaller in EG and intermediate in EU.

Regarding the slopes of the curves in figure 3 is possible to see in the RT curve a constant slope up to 50 cycles, which means an equivalent mass gain in all sets of 10 cycles. In the final 10 cycles, the slope of the curve decreases, which indicates a smaller increase in mass compared to the other cycles.

The curve in figure 3 corresponding to the EU, show different slope in the first 20 cycles, having a smaller mass gain in the next sets of cycles.

The curve of EG, shows a flattening pattern, revealing a lower penetration of salts. Due to the previous interpretation in granulometric characteristics of raw material and because it is glazed, the mass gain evolution was the expected.

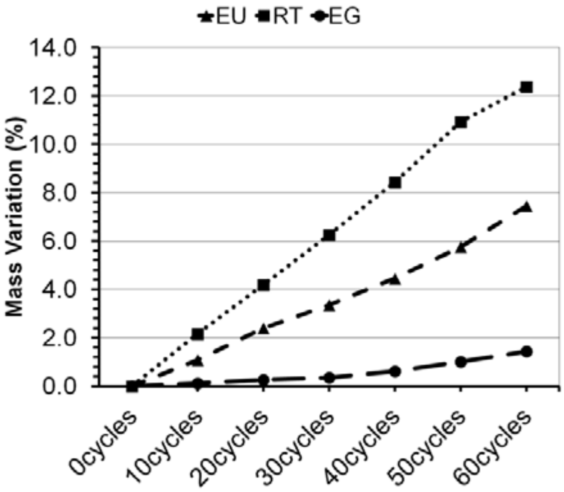

Figure 3 - Evolution of cumulative samples weight (before wash).

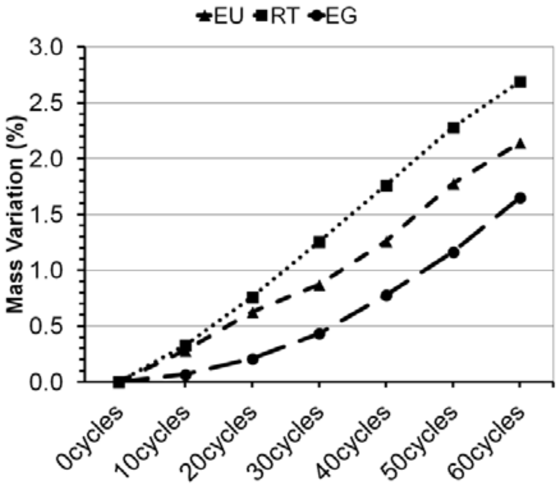

Figure 4 - Evolution of cumulative samples weight (after wash).

Figure 4 exhibits the mass gain in the three materials after their immersion in distilled water. This emphasizes the difficult of fired clay materials desalinization. The results may be explained by tiles distinct porosity characteristics (porometry, quantity, geometry and its connections to the exterior). These aspects can slow down the ingress of the distilled water and reduce the effectiveness of desalination.

After all cycles, efflorescences and salt deposits were macroscopically identified in RT, the efflorescences in EU and EG have distinct morphology (figure 5).

After desalination at 10 cyles, the RT samples show dark and white pitting and after 30 cycles, the density of this pitting becomes higher.

Through observation with the aid of a binocular microscope, other aspects may be identified. Before the desalination of the ceramics is possible identify different morphologies of NaCl salts on the surface. These different forms of crystallization have been already identified and studied (Arnold & Kueng, 1985; Arnold & Zehnder, 1985; Silva & Simão, 2009). The crystal habits are related to the type of material surface and the degree of solution saturation (Arnold & Zehnder, 1985). On RT surface, salt crusts, individual and well formed crystals and bristly efflorescences were identified. The two firsts morphologies are due to surface deposition of salts. In the case of the bristly efflorescences (some needlelike) it appears that crystals start their formation in the interior of the pores growing upwards to the surface. During this growth, the crystal applied stress into the surrounding material leading to their spalling and loss of material (figure 6).

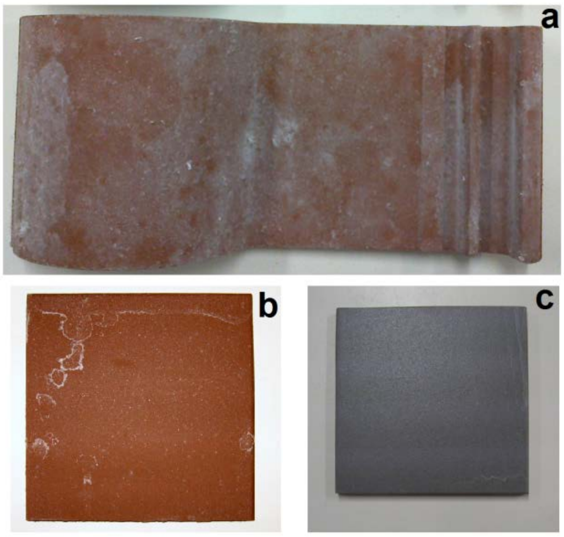

Figure 5 – Aspects of NaCl deposition on the samples: RT a); EU b); EG c).

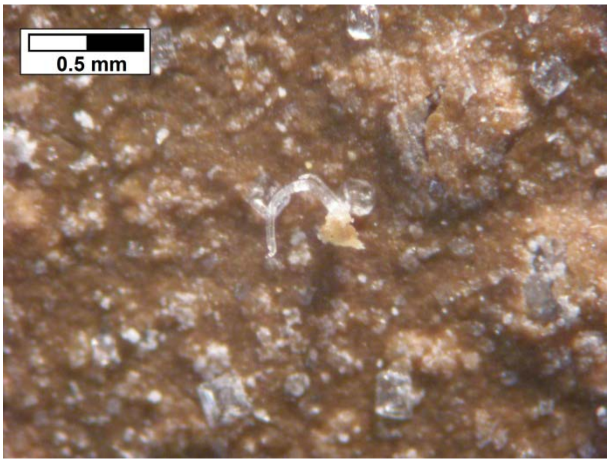

Figure 6 – Needlelike eflorrescence causing spalding.

Crystals with such aspect were not present in EU and EG. Possibly due to its low porosity some of the salts and crystallization forms are trapped inside the less accessible pores however, superficial formation of individual crystals were detected.

Throughout the various stages, some samples spots were monitorized. The sequence of figure 7 shows the evolution of a RT spot over the cycles. The visual differences are obvious, the cluster of quartz crystals cause spalling of ceramic matrix. This interface, matrix/quartz, seems to be a preferential zone to salt solution penetration and crystals growth.

Due to minerals susceptible to volume increase, different aspects of degradation were also detected. Salt can penetrate in cleavage planes of mica, such muscovite. Salt can also lead to oxidation of iron oxides like hematite. These volume increases result in visible pitting and spalling. Also the calcite, eventually present in the raw material, becomes lime by the firing temperature and when in contact with water converts into portlandite that present larger volume, causing the white pitting normally described as lime blowing (Elert *et al.* 2003). For the EU and EG the changes are not so evident. However, there are slight changes in areas near quartz crystals and loss of matrix material in the final stage of the aging test.

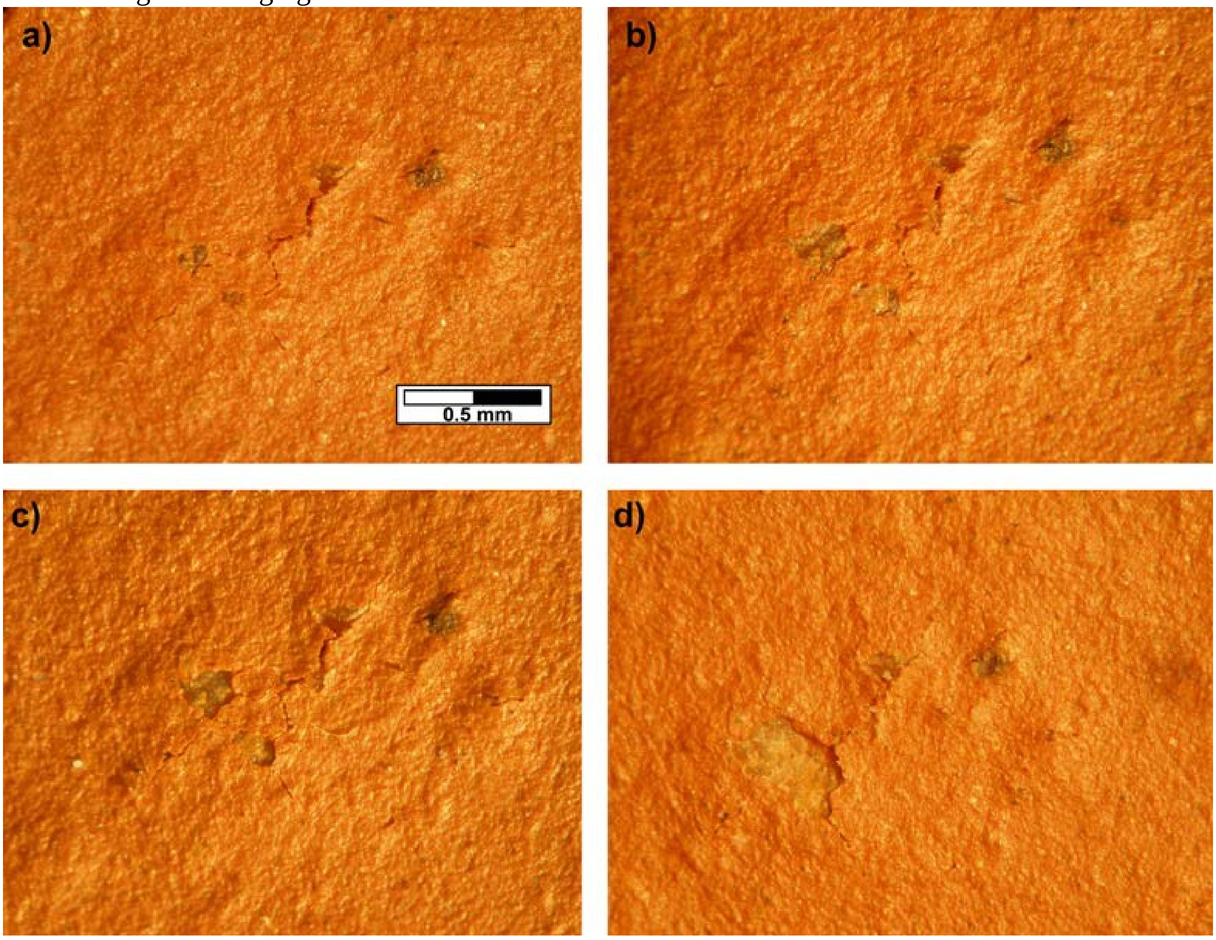

Figure 7 – Evolution at binocular microscopy of a RC spot.

X-ray diffraction

Analysing x-ray diffractograms of the three materials, stands out a peak corresponding to quartz, it is one of the most abundant mineral in all tiles. In the case of RT, hematite is also present, giving to this material its reddish colour. In EU and EG difractogram it is possible to identify mullite in their composition. The presence of this mineral is usual to occur in ceramics manufactured with higher firing temperatures.

The x-ray diffraction analyses after the 60 cycles of salt spray in tiles are similar when compared with the first diffractograms. However, in the case of RT, there is an important new peak, corresponding to the mineral halite, which is present due to the action of the salt spray. In the case of EU and EG difractograms, also occurs the presence of halite but with lower intensity peaks.

Resulting from minerals alteration there were no new peaks, thus there is no significant chemical alteration in the three ceramics.

Apparent porosity and water absorption

In first hand, the knowledge of apparent porosity and water absorption could give important clues in the evaluation of the bricks tendency to degrade upon salts action. The penetration and the residence of salts in the materials depend mainly on their pore structure (Benavente *et al.* 2003). Considering the relative values of water absorption for the three materials in figure 8, it can be seen that RT present the higher water absorption value, about 6.0%, followed by EU, 1.4% and finally by EG, 0.15%.

For RT the curve shows that, after 10 cycles, the water absorption suffered a significant increase of more than 0.5%. In the following cycles, the values are quite stable.

Concerning EU, after 20 and 40 cycles, the value increases linearly, to 1.9% and 2.2% respectively, with a stabilization in the last 20 cycles.

For the EG, the water absorption present a slight increase along all the 60 cycles. This seems to indicate that in clay bricks and tiles with lower water absorptions the effect of sea salt needs more time to a stabilize.

The values of apparent porosity in figure 9, can be relate with those described to water absorption. The evolution of the apparent porosity along the cycles was equivalent to the presented in figure 8 for water absorption.

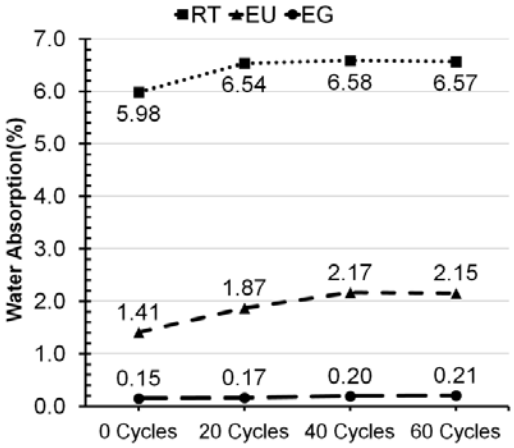

Figure 8 – Water absorption evolution of the three materials.

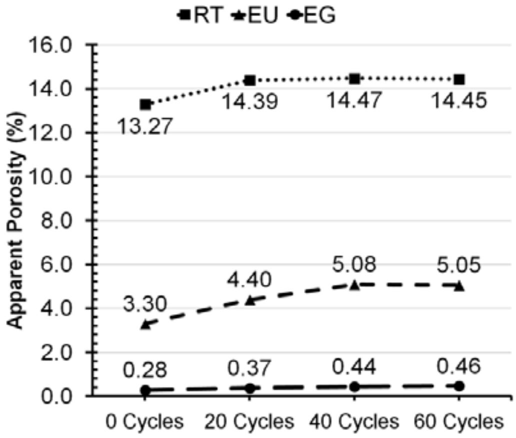

Figure 9 – Apparent porosity evolution of the three materials.

The increasing values in these two properties are explained by the, already mentioned, action of NaCl crystals growth. This cause superficial material loss and internal micro-cracks, which produce additional available voids for more incoming water in water absorption test.

Comparing the differences between the initial and final values of the three materials, it is easily detected that the samples with lower initial value have a higher rate of changes. In the case of water absorption RT, EU and EG exhibit decreases of 10, 52 and 40%, when compared to the initial state. For apparent porosity these values are 9, 53, 54%, respectively. From this point of view, the lesser porous material showed a high rate of degradation. Thus, the rate of physical damage by salt crystallization is also function of other parameters, such as the moisture supersaturation, magnitude of the repulsive forces between the salts and the confining pore walls, rates of elements supply, water evaporation and the pore size (Scherer, 2004). A higher amount of salts within the material is not sufficient to cause more damage and appears that ceramic materials with smaller pore size (EU and EG) are more favorable to supersaturation and contact between pore walls.

Modulus of rupture

The mechanical strength of fired clay materials is determined by the granulometric properties and mineralogical composition of the raw material. The manufacturing processes such as moulding features and firing temperature have also an important role in the ceramics final behavior. Figure 10 displays the modulus of rupture of the three types of samples. The RT, as expected, is the material that has the lower initial value of 19.2 MPa. On the other hand, the EG have the highest value of 51.5 MPa. The mechanical strength of the reference samples is consistent with the previous data, namely, the firing temperature, granulometric composition and the apparent porosities. The vitrified phase results from the fusion of the various components of the clay and is connected to the maximum firing temperature. Usually, higher vitreous phase result in higher mechanical strength.

With the evolution of cycles, the mechanical strength decay in all the three materials and after all the aging cycles. The exception is the RT, after 20 cycles of salt spray the strength decrease to 17.1 MPa, in the next 20 cycles the value increase and is followed by a new decrease. Show a final value of 18.1 MPa, which represents a 6% of loss in strength after the aging tests. This could be explained by a partial filling of the pores which causes an increase in compressive strength. It is known that under flexural load exists a compressive zone that could contribute to an increase in the overall flexural strength. However, to confirm this explanation it is required further investigation. The final value of modulus of rupture in EU was 23 MPa, which is a significant decrease after the aging tests, this represents a decrease of approximately 30%.

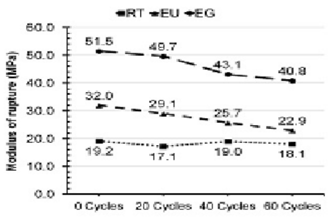

Figure 10 – Evolution of rupture modulus with the aging cycles.

In EG the action of the first 20 cycles results in a decrease of 2 MPa. However, the main loss of strength occurred in the followed 20 cycles where a value of 43 MPa was obtained. At the end of the aging tests, the modulus of rupture was approximately of 41 MPa, which corresponds to a total decrease of 20%. The effect of the salt spray had a clearly negative influence on the strength properties of these materials.

It is possible to note that the ceramics with higher initial mechanical strength had a higher rate of degradation. Thus, analogous interpretation to that made for the case of water absorption and apparent porosity can be performed. Elert *et al.* (2003) studied the deterioration by salt crystallization in clay bricks and concluded that relatively large pores are favorable to durability, which confirms these results and interpretations.

Conclusion

The salt spray action in modern facing bricks and tiles cause degradation. This degradation is expressed through physical and mechanical alterations.

The method for evaluating the degradation through weight loss, recommended by EN 14147, is not so appropriate for ceramics. From this perspective, the water absorption, apparent porosity and flexural tests proved to be suitable for quantifying physical and mechanical degradation.

Through visual inspection it was possible identify alteration forms in RT and EU. It was found that minerals with higher hardness (e.g. quartz) than the ceramic matrix and with dimensions close or greater than 0.5 mm on the tiles surface enhance the loss of material by spalling and pitting. When subjected to the salts crystallization their presence can be important to material performance by two reasons: An interface between the crystal and the ceramic matrix which facilitates the penetration of salt solution and a preferred zone for crystal growth. Different strengths between adjacent materials create heterogeneity. The stresses generated by crystal growth in these two materials results into a failure, usually of the ceramic matrix.

The minerals susceptible to swelling near the surface are also an important source of degradation.

The evolution of water absorption and apparent porosity were not favorable to the expected performance in the three materials. The salt spray cycles, produced an increase in water absorption and apparent porosity.

It was concluded by quantifying the mechanical properties, the existence of degradation at different scales between samples. In the two of the most important characteristics, water absorption and modulus of rupture, the ceramics with higher changes are the facing bricks. The strength showed a decrease of more than 20% and water absorption increased more than 40%. These observations allowed conclude that large pores have a minor role on the degradation, while a more severe damage may occur in the ceramics with a large amount of smaller pores.

References:

Arnold, A., Kueng, A. – Crystallization and habits of salt efflorescences on walls I: Methods of Investigation and Habits. Félix G (ed.) Proc. 5th Int. Congress on the Detrioration and Conservation of Stone, Lausanne, (1985): 255–267.

Arnold, A., Zehnder, K. – Crystallization and habits of salt efflorescences on walls II: Conditions of crystallization. Félix G (ed.) Proc. 5th Int. Congress on the Deterioration and Conservation of Stone, Lausanne, (1985): 269–277.

Benavente, D., M.A. García del Cura, *et al.* Salt influence on evaporation from porous building rocks. Const. Build. Mater. 17(2) (2003): 113-122.

Brocken H., Nijland T. - White efflorescence on brick masonry and concrete masonry blocks, with special emphasis on sulfate efflorescence on concrete blocks. Constr Build Mater 18 (2004): 315–323.

Cardell, C., Delalieux, F., Roumpopoulos, K., Auger, F., Van Grieken, R. - Salt-induced decay in calcareous stone monuments and buildings in a marine environment in SW France. Const Build Mater, 17 (2003):165-179.

Elert, K., G. Cultrone, *et al.* Durability of bricks used in the conservation of historic buildings - influence of composition and microstructure. Journal of Cultural Heritage 4(2) (2003): 91-99.

EN 10545-3:1995 -Ceramic tiles - Part 3: Determination of water absorption, apparent porosity, apparent relative density and bulk density. CEN.

EN 10545-4:2004 - Ceramic tiles. Part 4: Determination of modulus of rupture and breaking strength. CEN.

EN 14147:2003 – Natural stone test methods: Determination of resistance to aging by salt mist. CEN.

EN 14411:2006 - Ceramic tiles. Definitions, classification, characteristics and marking. CEN.

Galembeck, T., Simão, J., Silva, Z., Artur, A.C. - Effects of salty solutions in dimension stones from Southeast Brazil. II International Congress of Dimension Stone. Carrara, Italy: 517, 2008.

Garcez, N. – Sistema de inspecção e diagnostico de revestimentos exteriores de coberturas inclinadas. Master Thesis, IST, Lisboa, 2009.

Houben, H., Guillaud, H. – Earth Constuction: A comprehensive guide. ITDG Publishing. London, 1994.

IPCC - Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Climate Change 2001: The Scientific Basis. *Cambridge University Press*. UK, 2001.

Kuchitsu N., Ishizaki T., Nishiura, T. - Salt weathering of the brick monuments in Ayutthaya, Thailand. Engin Geol 55 (1–2) (2000), : 91–99.

Leeuw, G. – Sea Spray Aerosol Production Form Waves Breaking in the Surf Zone. J. Aerosol Sci.30 (1999): 63-64.

Lubelli B., Hees R., Groot C. - The role of sea salts in the occurrence of different damage mechanisms and decay patterns on brick masonry. Constr Build Mater,18 (2004): 119–124.

Lucas, J. – Azulejos ou Ladrilhos Cerâmicos. Descrição geral, exigências normativas, classificação funcional, LNEC, Lisboa, 2003.

Moser, K. – Towards the pratical evaluation of service life – Illustrative application of the probabilistic approach. Durability of Build Mater and Compon, 8 (1999): 1319-1329.

Ottosen, L.M, Pedersen A.J., Inge, R. Electrochemical desalination of salt infected limestone masonry of a historic warehouse. Proceedings of Structural Faults and Repair, 2012.

Ottosen, L.M, Pedersen A.J., Inge, R. Salt-related problems in brick masonry and electrokinetic removal of salts. Journal of Building Appraisal 3 (3) (2007): 181–194.
Parras, J. – Mineralogía y propriedades cerâmicas de pizarras paleozoícas de cuidad real. Ed. Uni. Castilla-La Mancha, 1997.
Rörig-Dalgaard, I., L. M. Ottosen, *et al.*. Diffusion and electromigration in clay bricks influenced by differences in the pore system resulting from firing." Const Build Mater 27(1) (2012): 390-397
Scherer, G. W.. Stress from crystallization of salt. Cement and Concrete Research 34(9) (2004): 1613-1624.
Silva Z.S.G., Simão J.A.R. - The role of salt fog on alteration of dimension stone. Constr Build Mater, 23 (2009): 3321–3327.
Silva, B.; Rivas, T., García-Rodeja E., Prieto, B. – Distribution of ions of marine origin in Galicia (NW Spain) as a function of distance from sea. Atmosp Environ, 41 (2007): 4396-4407.
Sokolar, R. and L. Smetanova, Dry pressed ceramic tiles based on fly ash–clay body: Influence of fly ash granulometry and pentasodium triphosphate addition. Ceramics International 36(1) (2010): 215-221.
Zezza F, Macri F. - Marine aerosol and stone decay. Sci Total Environ, 167 (1995): 123-43.