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EXPERIMENTAL EVALUATION OF WEATHERING OF THE BRICK MASONRY TO FREEZE AND THAW CYCLES

CARACTERIZAÇÃO EXPERIMENTAL DA DETERIORAÇÃO DE ALVENARIA DE TIJOLO A CICLOS DE GELO-DEGELO

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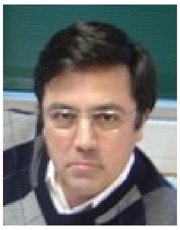


ABSTRACT

Given that the brick veneer walls are directly exposed to environmental conditions, it was decided to evaluate the decay of brick veneer masonry to freeze and thaw cycles. Besides brick masonry, mortar used in the construction of brick veneer and infill wall was also submitted to several freeze and thaw cycles. The assessment of possible decay on mortar specimens was carried out based on physical and mechanical properties and on visual inspection.

Palavras-chave: Brick veneer walls, bricks, mortars, freeze and thaw weathering, experimental testing

RESUMO

Dado que as paredes de tijolo face à vista estão diretamente expostas às condições ambientais, decidiu-se avaliar a degradação da alvenaria de tijolo em relação aos ciclos de gelo-degelo ciclos. Além da alvenaria de tijolo, a argamassa utilizada na construção de da alvenaria (face à vista e de enchimento) foi também submetida a vários ciclos de gelo-degelo. A avaliação da possível degradação em argamassa foi realizada com base nas propriedades físicas e mecânicas e na inspeção visual.

Palavras-chave: parede de tijolo face à vista, argamassas, ciclos de gelo-degelo, caracterização experimental

1. INTRODUCTION

Brick veneer masonry walls are frequently used as a façade finishing in residential construction in several countries in different parts of the world, mainly due to its aesthetic appearance, durability and its thermal performance. In general, brick veneer walls are separated from an air cavity in relation to a backing system to which it is attached mostly though steel ties. The backing system can be light wood or steel frames, structural masonry or masonry walls enclosed in rc frames and is considered as the primary lateral load-resisting system and the brick veneer is considered to be non-structural.

Brick veneer walls are directly exposed to environment and in cold environment they can be exposed if cyclic freeze and thaw cycles, which can contribute for its decay. In fact, freeze and thaw cycles are amongst the most significant weathering process causing severe damage to building materials (Nunes and Slížková, 2016). According to Çavdar (2014), when water begins to freeze in a capillary cavity, the increase in volume requires a dilation of the cavity equal to 9% of the volume of frozen water. If the pressure exceeds the tensile strength at any point it will cause local cracking. In repeated cycles of freezing and thawing in a wet environment, water will enter the cracks during the thawing to freeze again later and there will be progressive deterioration with each freeze–thaw cycles (Monteiro and Mehta, 2006, Çavdar, 2014),

Several work has been carried out on different types of materials to evaluate its freeze and thaw resistance, especially on rocks, mortar and concrete (Perrin et al. 2011, Arizzi et al., 2012). Lime mortars have presented durability problems mainly when exposed to weathering agents like water and freeze-thaw cycles (Nunes and Slížková, 2016, Veiga, 2003, Cao and Chung, 2002). The cement mortar has also been studied since long time in order to understand the deleterious effects that the exposition to freeze and thaw can cause on it (Marzouk, 1994, Biolzi et al. 1994).

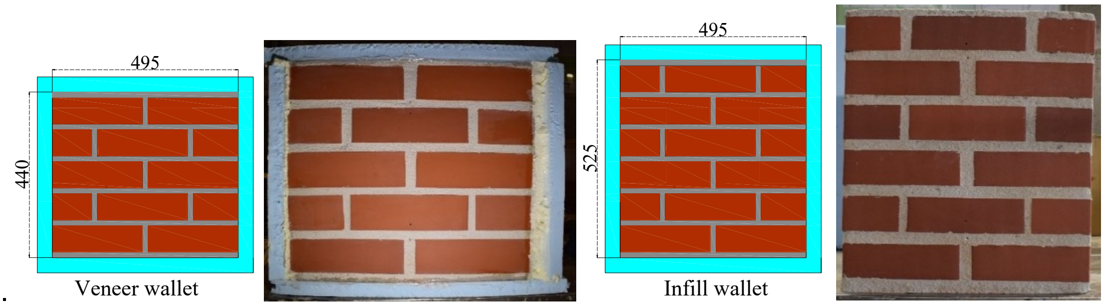
In the scope, an enlarged experimental characterization masonry materials was designed to evaluate the effect of freeze and thaw cycles in the decay of materials, namely mortars and brick masonry. The main experimental procedures and results are presented and disused.

2. MATERIALS

The mortars used in the assessment of the influence of freeze and thaw actions in its physical and mechanical behaviour are the pre-mixed water repellent cement mortar applied on masonry veneer walls and the general purpose mortar pre-mixed mortar M5 applied in the construction of brick masonry infill walls to which the brick veneer walls are often attached.

The main goal of using these two types of mortar was to understand the behaviour of a common mortar and of a hydrophobic mortar (veneer mortar) under the same freezing cycles. About 16 specimens with dimension 160mm x 80mm x80 mm were prepared for each type of mortar (EN 1015, 1999). From these, 8 samples were subjected to freeze and thaw cycles and 8 samples were used as reference. The samples were kept during the first day inside the moulds and were stored at 90 ± 5% of relative humidity for 6 days afterwards the samples. The mortar prisms were then stored until the starting of the tests under controlled environment conditions with a temperature of 20 ± 5ºC and relative air humidity of 60 ± 10%.

To characterize the behaviour of brick veneer masonry to freeze and thaw cycles, the vertical hollow bricks (237mm x 115mm x 70mm - length x thickness x height) used in the construction of brick masonry walls were combined with two types of mortar, namely the general purpose pre-mixed mortar of class M5 (infill wallet) and pre-mixed water repellent cement mortar (veneer wallet). The dimensions adopted for the brick veneer and infll wallets are presented in Fig. 1, defined to approximate the recommended dimension provide by the European standard EN 772-22 (2006) for masonry specimens to be submitted to freeze and thaw tests (between 0.25 and 0.5m^2). The samples were stored in laboratory environment with average temperature of 20 ± 5ºC and relative humidity of 60 ± 10% during 7 days. Then, the test panel was allowed to cure in ambient laboratory conditions for more 21 days until starting procedure.



(a) (b)

Fig. 1 – Tested masonry wallets using (a) veneer and (b) infill mortar (dimensions in mm)

3. EXPERIMETAL CAMPAIGN

3.1. Masonry mortars

The procedure used in freeze and thaw tests on mortar was based on CSN 72 2452 (1968). After curing for 28 days, the mortar specimens were dried until achieving constant mass at 60ºC according to standard EN 1015-11 (1999). After this, the samples were immersed in water at a temperature of 20 ± 5ºC until achieving constant mass. The freeze and thaw cycles procedure requires that the saturated mortar specimens reach a temperature of −20 ± 5◦C in a freezer in 4 hours and then thawed in water at ambient temperature of 20 ± 5◦C for at least 2 hours before performing another cycle (CSN 72 2452, 1968). In an attempt to accomplish this procedure, a freezer was adapted in order to carry out the freeze and thaw cycles in an automatic sequence accomplishing also the temperature ranges indicated in the standard. For this, an electric resistance, a water agitator, a ventilator, a pump and a heater were added to a freezer (Fig. 2).

(a) (b) (c)

Fig. 2 – Mortar freeze and thaw test: (a) global equipment, (b) developed software and (c) recipient with tested samples with pump, water agitator, heater and temperature sensors

The electric resistance enables to increase the temperature until a value that is compatible with the standard during the thaw cycle and the water agitator enables to have the water where the specimens are immersed at uniform temperature. The ventilator enables to have the internal environment of the freezer at uniform temperature and allow the renovation of air. The pump empties and fills the chamber with water during the thaw cycle. The heater is added so that the internal environment of the freezer during the thaw cycles achieve the range values recommended by the standard. A labview software application was developed to: (1) control the temperature in the freezer and enable the sequence of the freeze-thaw cycles automatic; (2) record the temperatures of the control sensors. The internal environmental temperature of the freezer and a temperature of sample centre were measured and compared by control temperature sensors. Preliminary tests were carried out to validate the testing procedure, being necessary to make some adjustments to obtain temperature readings according to standard temperature requirements within the required intervals. The freezing in the specimens is accomplished with the low air temperature that circulates in the freezer after the water is taken out the recipient, whereas the thaw is materialized with submersion of the samples in water. In the freezing cycle, the decrease in the temperature was not so powerful as should be to accomplish the target temperatures during the required period of time, being recorded some a variation of about 30% regarding to recommended temperature. Thus, 6 hours were defined as a suitable freezing and thaw period, see Fig. 3.

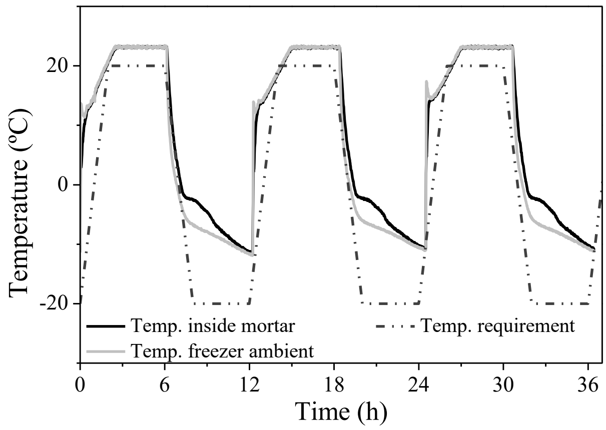


Fig. 3 – Freeze - thaw cycles records and requirement law for mortar specimens

For each type of mortar, 8 samples were subjected to the freezing cycles (F-T) and a group of more 8 specimens was used as a reference for the frost-exposed materials (No F-T). They were kept at room temperature in water for the whole time of the cycling procedure. Control of decay was carried out after 50 and 175 freeze-thaw cycles. Besides the visual inspection of the specimens, comparison of physical properties, namely porosity (EN 1936, 2007), water capillary absorption coefficient (EN 1015-18, 2002) in reference and tested specimens to freeze and thaw cycles. The same procedure was also followed regarding to the mechanical properties, namely flexural and compression strength (EN 1015-11, 1999).

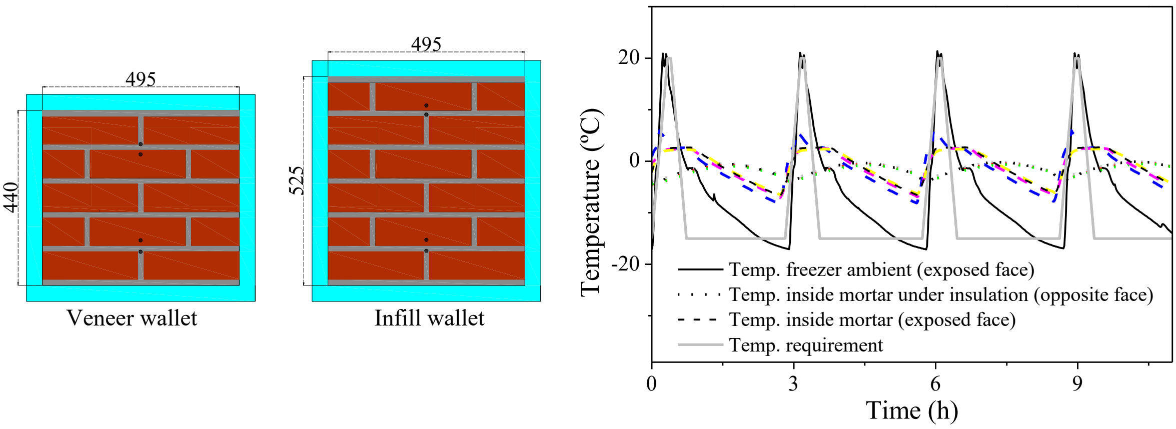
3.2. Brick masonry

Brick masonry wallets were subjected to freeze and thaw cycles following the standard that determine freeze/thaw resistance of clay masonry units as reference (EN 772-22, 2006). The masonry wallets were protected with insulation material with 40mm of thickness in all faces with exception of the face to be exposed to freeze and thaw cycles after 7 days of complete saturation. During the freeze and thaw cycles, the temperature distributions over the exposed face of the panel should be as uniform as possible. To get the time-temperature requirements suggested by standard, another freezer with higher dimensions than freezer used in mortar material was required. Once again, an electric resistance, a ventilator and a heater were added to the freezer (Fig. 4). The electric resistance and the heater enable to increase the temperature until a value that is compatible with the standard with the help of the ventilator that enable uniform internal environment temperature uniform and renovation of air. In this test, there is no submersion of specimens during all freeze and thaw cycles, only the pulverization with water on exposed face in each starting freeze cycle. For this, a water spraying system were applied to the freezer, distributing sprayed water in all face area. The air temperature was measured at a distance of 30 mm ± 10 mm from the centre of the exposed face by two temperature sensors and its average is taken as the test control measurement recommended in the standard.

(a) (b) (c) (d)

Fig. 4 – Masonry freeze and thaw test: (a) global equipment, (b) ventilated heater (c) spraying system and control temperature sensors and (d) developed software

It was decided to add more two temperature sensors in order to monitor different points on masonry mortar and compare it with the temperature distribution in the wallet. Two points in mortar and two points in the brick of each longitudinal faces were drilled and a thermocouple was introduced in each hole (Fig. 5a).



(a) (b)

Fig. 5 – Distribution of holes to apply the temperature sensors on wallets; (b) Freeze - thaw cycles records and requirement law for wallets specimens

According to the standard, the first freezing cycle should last for 6 h ± 5 min, whereas each following freezing cycle should be completed in 120 min (± 5 min). The air temperature measured at the distance of 30 mm ± 10 mm away from the centre of the exposed face should be between 20 °C ± 3 °C to -15 °C ± 3 °C in not less than 20 min but not more than 30 min. The temperature of -15 °C ± 3 °C should be maintained for a further 90 min to 100 min so that the total freezing period is 120 min ± 5 min. Regarding to thaw cycle, the total warm air period, including the period of temperature rise, should not be lower than 15 min and not more than 20 min ± 1 min, varying the temperature from -15 °C ± 3 °C to 20 °C ± 3 °C. The water spray period should last 120 s ± 10 s. The water was supplied at a rate of 6 ± 0,5 l/min.m with the test panel at a temperature between 18 °C to 25 °C. At the end of the spray period, 2 minutes are allowed for water to drain from the system.

A labview software application was also developed to: (1) control the temperature in the freezer and make the sequence of the freeze-thawing cycles automatic; (2) control the starting and the end of water spraying, as well as corresponding drainage time; (3) record the temperatures of the control sensors. Preliminary tests were carried out to validate the testing procedure, and the optimization of temperature readings according to the standard temperature requirements within the required intervals is presented in Fig. 5b. It is noticed that the material temperature did not achieve the control sensor temperature, as expected, However, it is considered that it achieved freezing and thawing temperatures in suitable stages. The rate of temperature of non-exposed and insulated face is much lower than to exposed face, as expected.

4. ANSLYSIS OF RESULTS

4.1. Mortars

In a first phase, the decay of mortar specimens was inspected through visual inspection. In case veneer mortar, after 50 cycles of freeze and thaw cycles, the rough surface layer of the sample disappeared, and the particles were stored in the container. The decay can be classified in level 1 due to very little damage caused by wearing. After 175 cycles of freeze and thaw cycles, higher loss of material is observed, especially at bottom face of the mortar specimens. The quantity of detached particles increased due to abrasion. The damage can be classified in level 2, being the fragments ≤10mm^2 by fragment (Fig. 6a). In case infill mortar, in half of samples, detachment of surface layer was seen after 50 cycles of freeze and thaw. The damage is classified in level 3 as the fragments are higher than 10mm^2 (Fig. 6b). No additional significant degradation was recorded in remaining samples not previous deteriorated after 175 cycles of freeze and thaw. Nevertheless, the quantity of sediments increased due to continuous superficial wearing. The level classification can be maintained in level 3 and thus. according to EN 12371 (2010) infill mortar could be considered das degraded. The mortar veneer was not considered degraded taking into account that only small rounding of corners and edges was observed. This does not compromise the integrity of the specimen and only detachment of small fragments (area≤10mm^2 by fragment) was recorded.

(a)

(b)

Fig. 6 – Visual aspect after freeze ad taw cycles; (a) veneer mortar; (b) infill mortar

In order to obtain a quantitative assessment of the influence of the deterioration induced by the freeze and thaw cycles, the variation of the physical (porosity and capillary coefficient) and mechanical (flexural and compressive strength) parameters during freeze and thaw tests was analyzed (Fig. 7). In case of veneer mortar, the porosity decreases about 7% at final of test on non-exposed samples and about 5% in the specimens subjected to freeze and thaw cycles (Fig. 7a,b). The porosity of infill mortar decreased about 4% and 3.6% for the reference specimens and for mortar submitted to freeze and thaw cycles, respectively.

Theoretically, the porosity should increase in F-T samples due to the loss of material. In principle the number and dimension of existing voids would be higher after the freeze and thaw cycles. However, the decreasing trend is seen both in specimens submitted to different test conditions. This can be explained by the process of curing of the specimens, which was developed under saturated conditions. Thus, taking into account all samples are immersed in water, the consequent accelerated hydration due to ageing and/or favourable conditions in water tank should explain the results observed. With the increasing of cement hydration degree and the consequent hardening of the material, the formation of hydration products results in the gradual decrease of the mean diameter of the capillaries and of porosity. In both types of mortar, the reduction of the porosity is lower in case of F-T samples, particularly in reference specimens. This means that the beneficial effect of the curing conditions is not overtaken by the harmful effect of freeze and thaw cycles. In addition, the porosity of the veneer mortar after freeze and thaw cycles is practically the same as the one observed in the reference specimens, which appears to confirm the lower harmful effect of the freeze and thaw cycles in this mortar. This effect is also reflected on the capillarity water absorption coefficient, which reduces about

57% and 73% after 175 freeze and thaw cycles in exposed and non-exposed samples respectively (Fig. 7c,d). The lower the thickness of the capillary channels, the higher the capillarity tension and consequently higher the height of absorbed water. This pressure depends on the moisture content, temperature, network and dimensions of the pores.

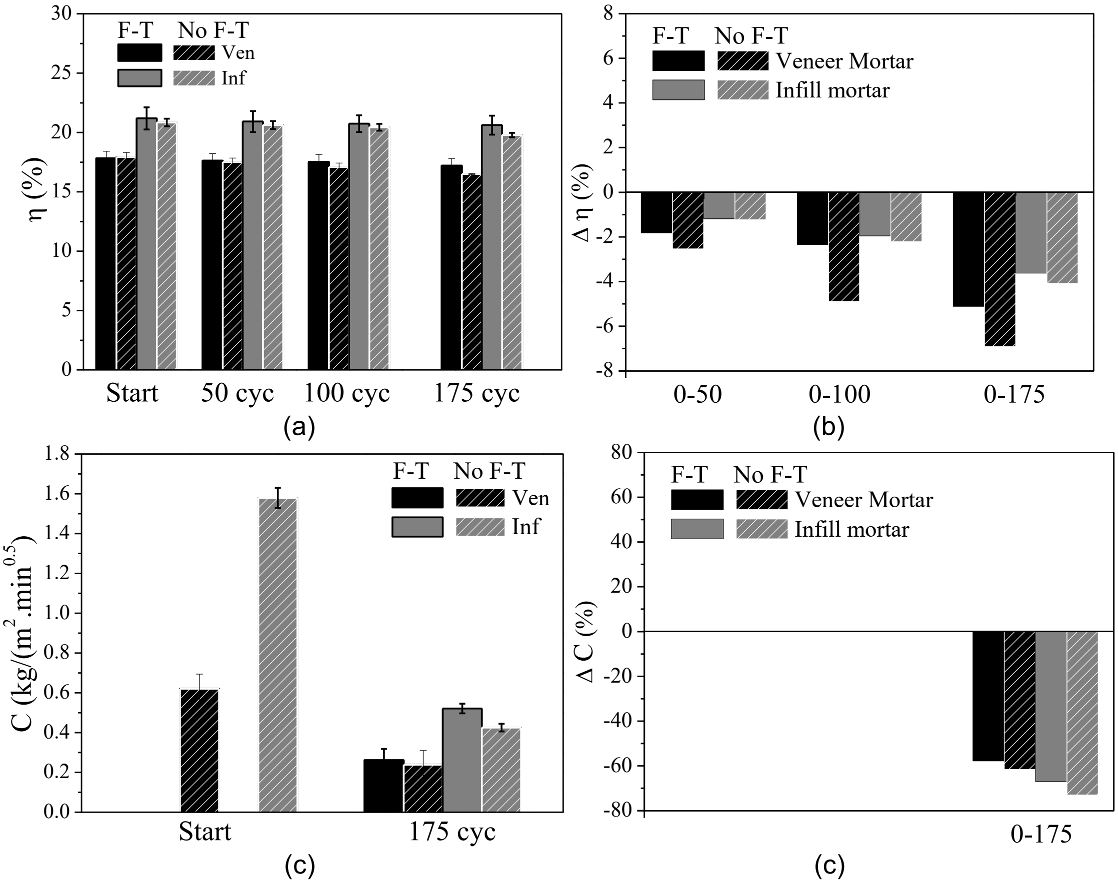
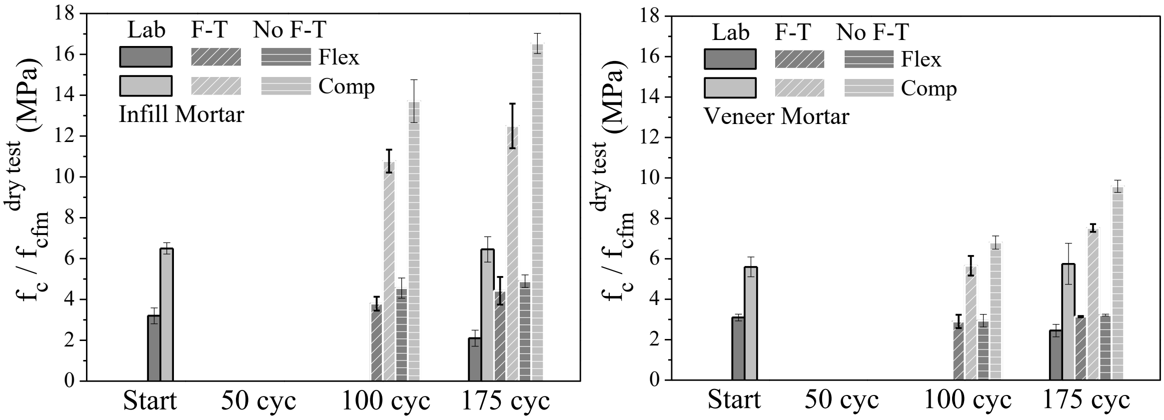


Fig. 7 – Variation of the physical properties; (a) porosity; (b) water capillary coefficient

The average values of the flexural, f_{cfm}, and compressive strength, f_c, obtained for the two types of mortar before and after the freeze and thaw cycles is presented in Fig. 8. From the results, it is possible to observe that the mechanical flexural and compressive strength increased in both of types of mortar with increasing number of freeze and thaw cycles. The increase of the compressive strength in infill mortar samples was between 154% No F-T samples and 92% for F-T and after the freeze and thaw cycles. For veneer mortar, the increase on the strength was about 35% in exposed and 70% for non-exposed samples. Regarding to the flexural strength, the effect was not so significant, being the increasing considered neglected in case of veneer mortar. It was also observed that practically there is no increase or decrease of strength between samples at test starting and at final test, both kept in laboratory conditions. This appears to indicate that the internal structure of mortar changed especially due to curing wet conditions.



(a) (b)

Fig. 8 – Variation of the flexural and compression strength; (a) infill mortar; (b) veneer mortar

4.2. Brick masonry

The effect of freeze and thaw cycles on the masonry wallets is here mainly described based on inspection, see Fig. 9. The same scale of deterioration suggested in EN 12371 (2010) was also used to characterize the brick masonry specimens. When the masonry infill wallet achieved 50 cycles, the covering surface was degraded in all area, having some regions more affect as illustrated by zone 1, 2 and 3.

The surface presented an irregular and porous layer with holes and disintegration of material at the corners and edges due to freeze abrasion. It can be classified by level 3 due holes or detachment of small fragments higher than10mm2 by fragment. After 350 cycles, the mortar damage almost remained constant. In bricks of zone 1, salt efflorescence t was identified caused by soluble salts coming from mortar.

According to EN 12371 (2010) both masonry typologies could be considered degraded. The masonry veneer wallet achieved the degradation level 3 after 400 cycles and the masonry infill wallet achieved the degradation level 3 after 50 cycles. In both masonry wallets, the degradation occurred at the mortar joints and interfaces with brick units, revealing the importance of the type of mortar for the deterioration process during the freeze and thaw cycles. However, the final damage at 400 cycles is very different between the wallets. On the one hand, the degradation of the veneer wallet was caused by volumetric expansion, possibly as the result of water frozen and/or chemical reactions inside the water repellent mortar. On the other hand, the degradation of the infill wallet is mainly attributed to early abrasion and disintegration due to the freeze and thaw cycles, resulting from the more porous and weaker structure of the infill mortar.

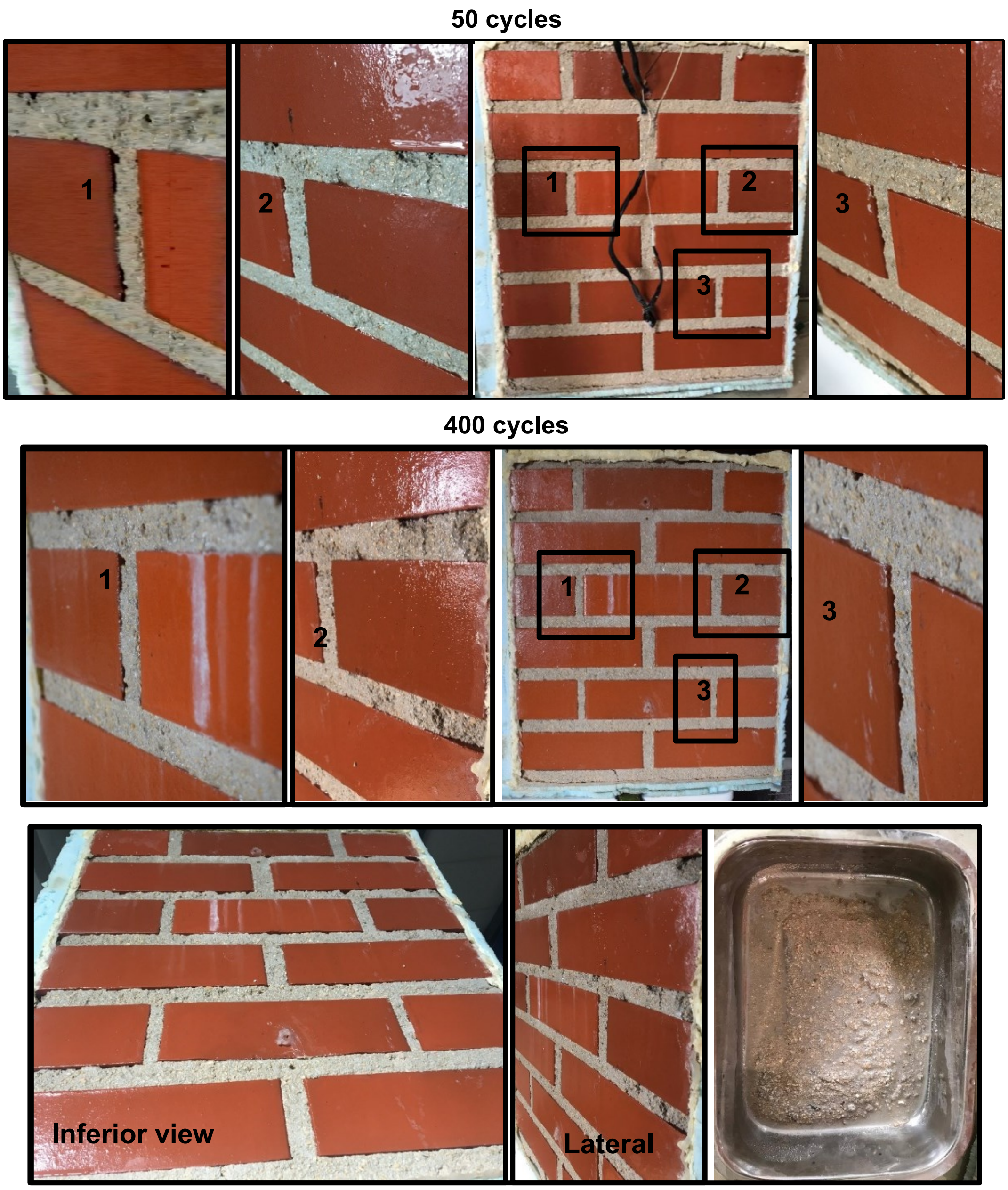


Fig. 9 – Visual aspect of the brick veneer wallets after freeze and thaw cycles

5. CONCLUSIONS

This work presented and discussed the results obtained in an experimental campaign of cyclic freeze ad thaw of masonry mortars and brick masonry. Many past research works presented the degradation of different types of material as concerning the appearance as well as internal properties. Nevertheless, in this study, other behaviour trend was obtained in terms of freeze and thaw resistance. While the visual degradation and disintegration of superficial layer have been detected, especially on infill mortar, the internal structure did not reveal loss of mechanical capacity. Unexpectedly, it was recorded an increase of mechanical properties, being achieved almost 100% of increase on compressive strength of infill mortar. This result may be attributed to accelerated hydration due to ageing and/or favourable conditions in water tank, avoiding the mixture water evaporation and improvement the hardening process. The remaining studied physical parameters reinforce this trend, being observed the decrease of porosity percentage and capillarity water absorption coefficient.

6. ACKNOWLEDGMENTS

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