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Efflorescence on clay bricks masonry: towards a new test method

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ABSTRACT

Efflorescence on clay bricks masonry used for veneer wall makes up a real problem appearing frequently just after the building implementation. Even if it affects only the aesthetic of the building, their baneful consequences are however indisputable both on the economical point and the quality concept in the building art. Except some intern laboratory procedures, there aren't any normalized test methods at the European level that take at the same time the clay brick and its mortar into account in the displaying of the efflorescence phenomenon. Now, most of the efflorescence's studies show that the interaction between these two elements is responsible for the efflorescence apparition. In Belgium, the national norm tests only the brick sensibility without evaluated the exchanges with the hydraulic binders material. In this article, an efflorescence test responding to these exigencies is presented. This test is the result of a research based on the understanding of the efflorescent salts apparition mechanism and the reproduction of this mechanism on laboratory samples. This reproduction has been done thanks to the precise determination of each parameter defining the different phases of this salts apparition mechanism: implementation, curing, humidification and drying. Collated to a great number of real cases, the test is now under validation.

The research, of which the goal is to present an efflorescence test in a new evaluation method of the brick/mortar assembly eventually normalizable at the European level in order to complete test method on masonry norm, proceeds from collaboration between the Belgian Building Research Institute and the Belgian Ceramic Research Centre.

KEYWORDS

Efflorescence, salt, masonry, brick, mortar

1 INTRODUCTION

Efflorescence appears generally on the surface of veneer wall build with porous material as clay bricks under an aspect of deposit of white powdery or foggy salts. The baneful consequence of this salt apparition is considered mainly as an aesthetic problem. This phenomenon often arrives just after the end of the construction (see 'Fig. 1') always generating confusion in the attribution of responsibilities between the different parties involved: brick provider, mortar provider, contractor, designer and customer. Sometimes, efflorescence appears few years after the end of construction leaving the building owner face to questions about cleaning or maintenance. In some cases, this salt apparition can be very persistent and hard to remove [Brocken *et al.* 2004].

Figure 1. Example of efflorescence apparition at the end of work.

Unfortunately, up to date, there are no recognized procedures at national or European level allowing to prevent the risk linked to this nuisance and protecting the building actors from litigations. Therefore, the Belgian Building Research Institute and Belgian Ceramic Research Centre have entered upon a study to define a new test procedure in order to characterize the efflorescence sensibility of a brick/mortar assembly. Because of the phenomenon is linked to the interaction between the brick and the mortar, it was indeed really important to study the assembly and not the two elements separately. This research is then supported by the two industries (brick and mortar providers).

The research methodology has been at first to understand the efflorescence apparition mechanism in order to find its sensibility parameters, then to carry out laboratory experiments in order to settle these parameters to their critical value and finally to obtain a reliable test procedure.

2 EFFLORESCENCES APPARITION MECHANISM

Efflorescences are the demonstration of soluble salts cristallisation at the surface of porous materials, due to the migration of solutions induced by evaporation. The most encountered efflorescences on masonry are due to the presence of soluble sulfates of Na, K, Mg and Ca [Barquin *et al.* 1996]. They are resulting from the interaction of bricks with hydraulic binders assemblies. In clays that are used in the manufacture of bricks, we usually find sulphides and especially pyrite. These sulphides become oxydated during firing to form SO_3 species that can react with the basic oxides of the clay. They form sulphates such as $CaSO_4$, Na_2SO_4, K_2SO_4 and $MgSO_4$. The last three sulphates are dissociated when the firing temperature exceeds 950°C but the calcium sulphate needs a temperature of at least 1200°C to be dissociated. However, the firing temperature of bricks varies from 950 and 1200°C so only $CaSO_4$ can still be found sometimes in bricks, but in very low amounts. In cements, oxides such as Na_2O and K_2O form hydroxides (NaOH and KOH) after the mixing. As cements usually contain gypsum ($CaSO_4.H_2O$) added to control setting, it can react with the hydroxides to form Na and K sulphates by the following reaction:

$$CaSO_4 + 2\ NaOH = Na_2SO_4 + Ca(OH)_2$$

Usually gypsum is bound in ettringite during hydration. But, if some $CaSO_4$ is present in the brick after firing, it can also combine with hydroxides and form alkali sulphates that will precipitate as efflorescence. The efflorescence formation is thus a complex phenomenon that also depends on external physicochemical parameters such as the implementation type, the curing duration, the humidification duration and the drying way. For the implementation, the nature of the components, the geometry of the assembly, the moisture of the brick and the mortar consistency are important to control. The duration of the curing is important to take into account as it shows the influence of a first rainfall on masonry after implementation and allows the migration of the available alkali in the assembly. The duration of the humidification is also paramount to allow a good homogenisation of alkali into the assembly, from the mortar into the bricks. Finally, the drying conditions have to be as close as possible to the real meteorological conditions encountered during the period when efflorescence appears on masonry. All these parameters have been investigated and adjusted to define an efflorescence test on assemblies in order to obtain results close to those observed *in situ*.

3 EFFLORESCENCE TEST SET UP

3.1 Materials choice

In order to set up the efflorescence test, we have chosen relevant building materials in accordance with the sector. These materials are considered to be representative of the veneer wall market offer.

Four bricks have been selected with respect to their fabrication process (handmade and extruded bricks) and sulphate concentration (high and low). In Table 1, we give the bricks characteristics and their identification.

Brick	*Low [SO_4^{--}] (<0.15 % wt)*	*High[SO_4^{--}] (>0.5 % wt)*
Extruded	V	Q (0.66 % wt)
Handmade	B	S (1.95 % wt)

Table 1. Overview of the selected bricks characteristics.

When tested according to the norm NBN B 24-209, only the brick V shows efflorescence sensibility. We have chosen to build the assembly with dry bricks for the test result reproducibility.

The composition of the different mortar types has been chosen in consultation with the FeMO (The Belgian Mortar Federation) to cover the building mortar possibilities and is given in Table 2.

Mortar	*Composition*
M11	CEM I 42.5 T HES + river sand
M12	CEM II 32.5 N + river sand
M13	CEM III 32.5 N LA + river sand
M14	Dry ready for use mortar

Table 2. Overview of the selected mortars characteristics.

The mortar is prepared with 'main water' and the water quantity has been determined by the norm EN 1015-3 in order to obtain a consistence of fresh mortar of about 2.1 (with the flow table). This consistence allows to work with dry bricks. With this brick and mortar choice, sixteen different combinations will be used for the laboratory experiments.

3.2 Optimisation of the test parameters

3.2.1 Implementation

The test has to be carried out on an assembly brick/mortar characterized by a shape which is representative for a masonry wall. Therefore we have designed an assembly composed of three bricks and three mortar layers and that respects the brick/mortar proportion of a normal wall. The mortar mix is prepared according to EN 1015-2 and the mounting is done in laboratory conditions. At the end of it, a mass is placed on its top in order to increase the adherence between the brick and the mortar during all the curing phase. This assembly is represented at the 'Fig. 8'.

3.2.2 Curing

The curing duration is an important parameter to take into account as it shows the influence of a first rainfall on masonry after implementation. To determine the time needed to the alkali to be available within the mortar for migration in the assembly, we have tested several curing durations (between 4 and 28 days) on mortar bars first. The concentrations in Na and K have been measured after the various curing durations by ICP after leaching in water. It has been observed that the evolution of the mortar structure during curing has no influence on the availability of Na and K and that the concentrations are similar after only 4 days of curing.

We have then tested different curing durations on small assemblies. One brick has been cut into three parts, one was kept as reference and the two others were implemented into a small assembly represented in 'Fig. 2'.

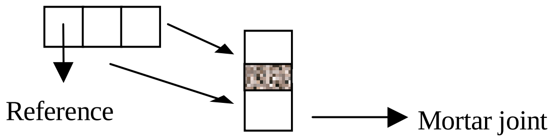

Figure 2. Small assembly used to determine the humidification parameter.

After a certain time, the assembly is put into a drying oven at 105°C to stop the migration of Na and K. The small assemblies are then cut into slices as shown on 'Fig. 3'. The reference piece is also cut into 3 slices. Each piece is ground, leached into water and Na and K are analyzed by ICP.

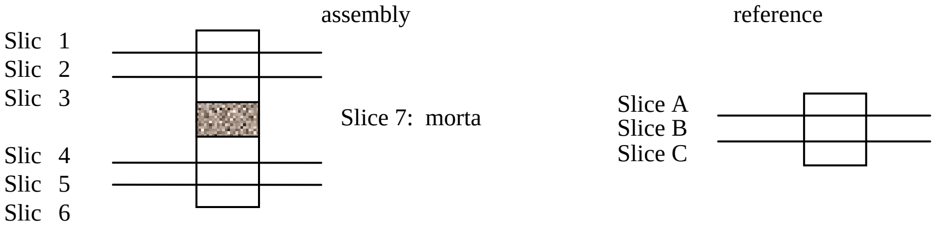

Figure 3. Slicing of the assembly and the reference before leaching and analysis.

It has been enhanced that after 14 days, the availability of Na and K is the highest one as shown on 'Fig. 4'. Moreover, at that time, the strength of the assembly is sufficient for further handling. The duration of the curing has then been chosen to be 14 days.

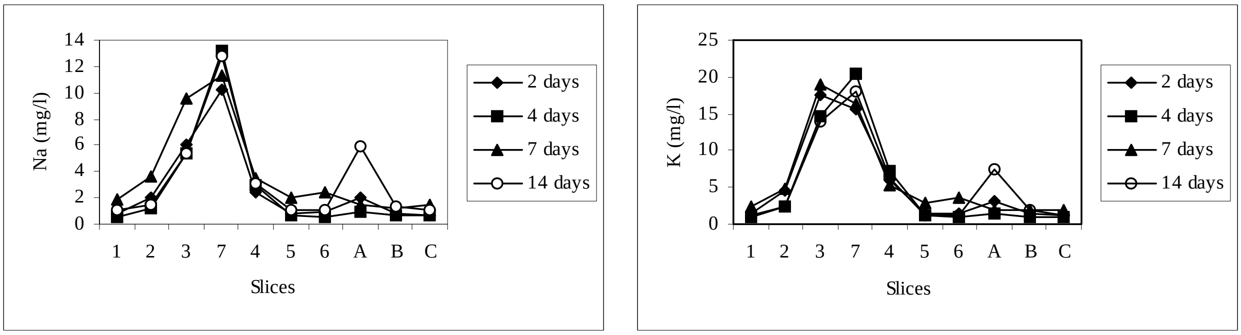

Figure 4. Concentrations of Na and K in the assemblies for various curing durations. Slices A to C correspond to the reference brick pieces.

3.2.3 Humidification

The humidification aims to obtain a good homogenisation of Na and K from the mortar into the assembly. It is then necessary to find the most appropriate duration of humidification. We have conducted similar tests as for the determination of the curing duration except that the small assemblies have been put into a tray within a constant 3 mm water layer after curing from 2 to 28 days. The rest of the experiment is similar.
The results show that after humidification, Na and K are leached from the mortar and decrease from one order of magnitude already after 7 days. The concentrations homogenize into the assembly and are higher into the brick slices of the assembly than into the reference brick slice. We also see that the longest the duration of humidification is, the lowest the Na and K concentrations in the mortar layer are (slice 7) as shown on 'Fig. 5'.

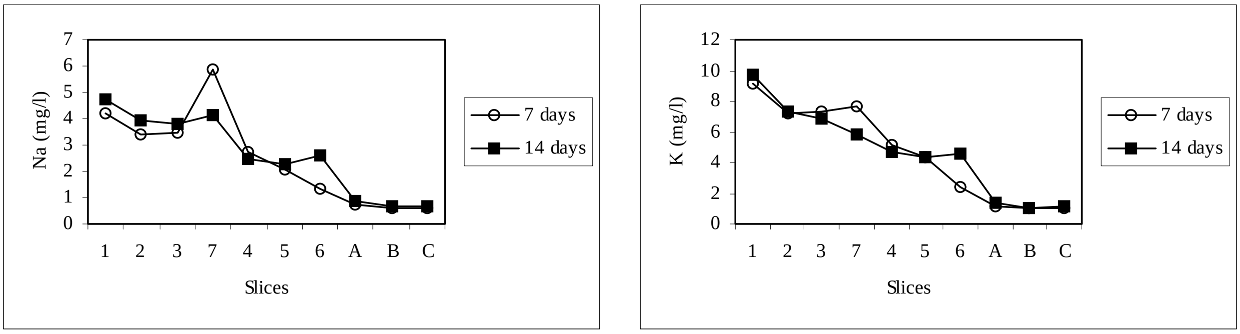

Figure 5. Concentrations in alkali within small assemblies after 7 and 14 days of humidification. Slices A to C correspond to the reference brick pieces.

So, in conclusions, the humidification time has been chosen to be 14 days to obtain a good homogenisation of the alkali into the assembly.

3.2.4 Drying

The optimisation of the drying conditions is really important. A too hard drying could carry away the crystallisation inside the brick and not on the surface. A too light drying could not cause crystallisation. To find out the optimal drying conditions, we have used an exposure site (shown in 'Fig. 6') with among other the selected brick/mortar combinations except the combination with the mortar M14. For each of them, two walls, one in the SW and the other in the NE direction, are built. The walls are 65 cm wide and 1m high. The three last layers of the wall are not assembled with mortar but by a rubber joint to see the behaviour of the brick alone.

Figure 6. Exposure site.

Near this exposure site, a meteorological station records every ten minutes the climatic conditions: temperature [°C], relative humidity [%], wind direction, wind speed [m/sec] and sun radiation [W/m²K]. Every day, a visual survey allows to see which wall shows efflorescence. This information is completed by three webcams that record every hour the evolution of three walls assumed to be really sensitive to the efflorescence apparition. Finally, some walls are fitted out with thermocouples placed inside the masonry in order to evaluate the thermal gradient. Three thermocouples by wall are used: one on the surface, one in the centre and one near the back of the wall.

All this information allows to assess the favourable drying conditions to the efflorescence apparition. These conditions are closely linked to the couple 'temperature/relative humidity' of the air that will determine what we call further the 'Air Drying Power'. The ADP [g/kg] is basically the water vapour quantity that the air can still absorb before reaching the dew-point and it is calculated by the difference between the maximal water content 'Xs' [g/kg] (depending on the air temperature) and the water content 'x' [g/kg] (depending on the temperature and the relative humidity of the air). Thanks to the exposure site monitoring, it is possible to determine the ADP and to couple it with the visual survey to find the ADP critical value above which the efflorescence always appears.

'Figure 7' shows an example of the coupled visual and ADP data. The survey is here reported for a period of three days in September 2002. The 3rd and the 5th September, the ADP was more than 9 g/kg and the pictures, taken at the middle of the day, show that there is efflorescence on the wall. On the other hand, the 4th September the ADP was less than 4 g/kg and the picture for the same wall doesn't show efflorescence.

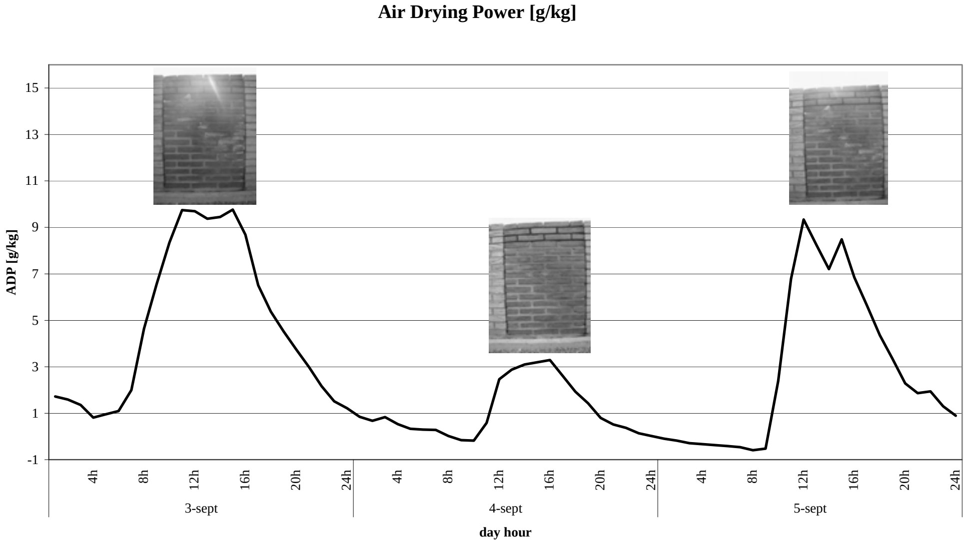

Figure 7. ADP graphic coupled with visual data of one wall of the exposure site.

With two years of recorded data, we have now the knowledge of the ADP critical value above which the efflorescence apparition is almost certain. This ADP value is around 10 g/kg of air. With this ADP value, it's possible to define 'temperature/relative humidity' conditions easy to realize in a laboratory by using the humid air equation [Carpentier *et al.* 1982]. Some examples are given in table 3.

Couple possibilities	*Temperature [°C]*	*Relative humidity [%]*
1	25	50
2	20	32

Table 3. Temperature and relative humidity carrying away an ADP of 10 g/kg.

Influence of temperature gradient. It is important to note that in case of important differences between the ambient air temperature and the wall surface temperature, the ADP critical value must be considered in the air layer close to the surface of the wall. For example, we can have general climatic conditions with a weak ADP of about 4 g/kg (10°C, 50% HR for instance) but sun radiations that lead to an ADP of about 10 g/kg on the masonry surface. These conditions are really favourable to the efflorescence apparition because of a thermal gradient builds up between the centre and the surface of the masonry. These conditions are often present during the spring when efflorescence appears on the masonry. Further investigations are currently realised in order to reproduce in the drying phase this temperature gradient by switching on IR lamps three hours a day. The IR lamps are situated fifty cm upper the surface of the assembly. The room hydrothermal conditions are 10°C, 50 % RH and during the IR lamps radiations, the surface of the assembly reaches 30°C. Up to date, the results seem to be very attractive by showing an increase of sensibility for the tested combinations.

3.3 Efflorescence test protocol

The test protocol is directly in accordance with the results of the optimisation phase experiments. Figure 8 shows the different test steps and the Table 4 gives the parameters of each test phases.

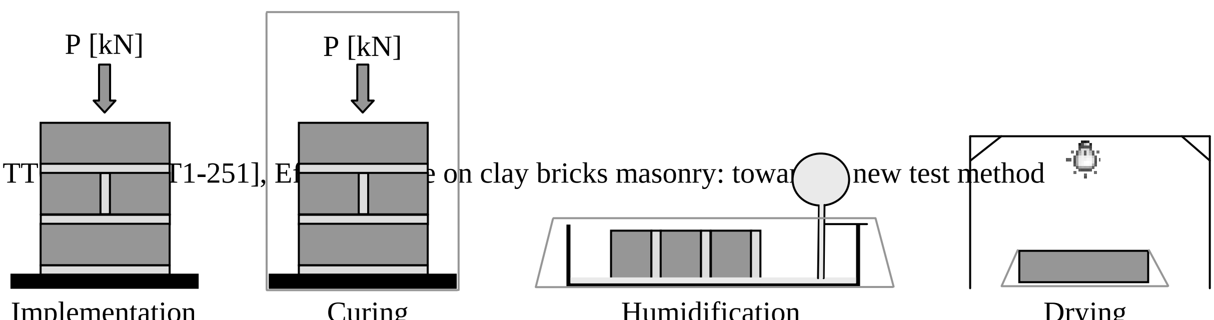

Figure 8. Pictures of protocol phases.

Protocol phases	*Duration [day]*	*Conservation conditions*
Curing	14	under plastic
Humidification	14	under plastic
Drying	until constant massa	25°C; 50% RH

Table 4. Test phases parameters.

At the end of the test, we proceed at the results evaluation following this scheme:
Take a picture of all assemblies;
Select the assemblies presenting efflorescence upon more than 5% of their surface;
Rub efflorescence with a humid sponge three times;
Wait fifteen minutes;
Note separately the assemblies without efflorescence or less than 5 percent of the assembly surface, the assemblies with efflorescence that doesn't appear after the humid sponge rubbing and the assemblies with efflorescence that appears after the humid sponge rubbing.

4 TEST RESULTS AND VALIDATION

In order to assess the reproducibility of the method, each combination has been tested five times on the sixteen combinations and the results are given here under on table 5. For the validation, we have opted for two different ways: the exposure site (presented here above) and the observation of real cases collected in a data base.

4.1 Exposure site

With a survey of two years, we have accurate information concerning the most sensible brick/mortar combinations to the efflorescence phenomenon among the research combinations. This information constitutes a validation base for the laboratory test results.

The table 5 contains the comparison between the test and the exposure site results in terms of apparition percentage. For the test, the percentage is the ratio between the apparition's number and the tests number multiplied by 100. For the exposure site, the percentage is the ratio between the number of days where efflorescence is detected and the total number of days where the site is visited multiplied by 100.

Apparition	*M11*				*M12*				*M13*			
percentage	*B*	*Q*	*S*	*V*	*B*	*Q*	*S*	*V*	*B*	*Q*	*S*	*V*
Test [%]	40	**20**	**80**	100	**60**	**0**	**100**	80	80	**20**	**100**	**20**
Exposure Site [%]	54	**8**	**61**	12	**27**	**6**	**41**	9	16	**12**	**41**	**0**

Table 5. Comparison between test and exposure site results.

The daily visual survey of the exposure site is done sometimes during a humidification phase (just after a rain); so, the percentage has to be consider differently between the site and the test. We give in the table 6 the agreement between the two.

Gravity	*Test apparition [%]*	*Exposure site apparition [%]*

High	[100 - 80]	> 30
Medium	[60 - 40]	[30 - 15]
Low	[20 - 0]	< 15

Table 6. Agreement between the test and the exposure site results .

The analysis of he Table 5 shows that the test and the exposure site are inclined to reveal the same combinations sensible to the efflorescence (in the table, the results from the same gravity category are in bold), except for the combinations with the brick V for which the results are really different. In fact, efflorescence on the brick V contains gypsum (detected by X Ray Diffraction analysis) and this salt is very sensible to the humidity [Muzzin 1982]. The test drying conditions are sufficient to see the gypsum when the external conditions are unusually favourable.

4.2 Real cases

Some Belgian contractors act at our request a data base with building case that presents efflorescence. The latest validation phase will be to apply the efflorescence test with the bricks and mortars of the data base in order to verify that the test results confirm the real case establishment. Currently, we have more than seventy cases.

5 FUTURE PERSPECTIVE

A new efflorescence test method is currently established after having improved his constitutive parameters with laboratory experiments. The test results confrontation to the behaviour of an exposure site built with the same combinations shows that the test is in accordance with it. The future perspectives concern an improvement of the drying phase by using IR lamps in order to cause a thermal gradient between the centre of the assembly and its surface and then to collate the test to a great number of real cases. Finally, the test method will be proposed at the European normalisation level in order to complete the masonry norm.

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