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WHITE EFFLORESCENCE ON BRICK MASONRY: TOWARDS PREDICTION OF EFFLORESCENCE RISK

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Abstract

Efflorescence appears as a mostly white and thin, foggy salt deposit on the surface of porous building materials. It often occurs on masonry façades, and depending on its intensity, changes the colour impression and appreciation of the façade as a whole.

Up to now, the building industry has not found a pragmatic remedy to this phenomenon. Moreover, no reliable tools are available to predict efflorescence risks. Therefore, TNO and associations representing the Dutch masonry industry have initiated a project that aims at the development of test procedures for determination of this risk. The project is carried out in several stages following a genetic approach based on primary analysis of field data. This paper gives an introduction to the genetic types of efflorescence encountered during the field study, and a more detailed discussion of one of these types, with results of a preliminary efflorescence test.

Key Words

Efflorescence, typification, process-analysis, prediction

1 Introduction

Efflorescence often occurs on masonry façades made of brick or concrete masonry blocks. In some cases, it appears directly after construction (Fig. 1), generating controversy between parties involved about appreciation and acceptation of the work, appropriate cleaning methods and associated costs. In other cases, efflorescence starts to appear after a couple of years (Fig. 2), leaving the current building owner with questions about damage potential of the phenomenon and appropriate maintenance of the façade. Generally, efflorescence is considered as an aesthetic phenomenon only. It has been observed for decades on masonry works everywhere in Europe, and has proved to be very persistent and hard to remove in many cases.

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Figure 1. Early efflorescence of soluble alkali sulphates directly after construction of housing blocks.

Figure 2. Efflorescence of gypsum that starts to appear after a couple of years

Efflorescence appears when wet walls dry and salts dissolved in the pore solutions accumulate near the surface. The essential role of water is evident: It is needed for dissolution of components of the efflorescing salt, as well as for their transport between brick or concrete block and mortar joint, and, finally, to the masonry surface. Though this seems straightforward, detailed knowledge and understanding of actual chemical reactions and transport mechanisms are lacking so far. Both brick or concrete blocks and mortar have typical constituents that could be the source of components of efflorescing salts, and exhibit their own typical hygric characteristics that, alone or in combination, may favour the development of efflorescences. Lack of understanding of the interaction of all these parameters, chemical composition, water transport characteristics and external influences (such as climate), makes it impossible to define solutions to this problem and to develop appropriate performance tests. Therefore, TNO has initiated a project that aims at the development of masonry and concrete products with a low efflorescence risk, i.e. showing no or a hardly noticeable level of efflorescence. The project is carried out in collaboration with all major market parties in the Netherlands.

Several hypotheses about the cause and mechanism of white efflorescence and contributing material parameters have been proposed in literature, and a systematic laboratory approach to successively eliminate individual parameters may be proposed. However, the range in chemical and mineralogical composition and hygric characteristics of individual materials is very large. Therefore, it was decided to choose a genetic approach, based upon careful analysis of field data (objects exhibiting efflorescence), of which construction details, timing of efflorescence development, exposition conditions were known, and both original, unused materials and applied

materials could be obtained for laboratory analysis. Below, an introduction is given to the genetic types of efflorescence encountered during this stage of the project. Additionally a more detailed discussion will be provided of one special type, viz. early sulfate efflorescence on masonry blocks.

2 Background

Efflorescence on masonry is generally formed by (hydrated) Na-, K-, Ca-sulphates or carbonates, with more rarely Mg-sulphates or other salts, usually due to specific conditions related to exposition (nitrates). Single and double salts commonly encountered are thenardite, Na_2SO_4, glaserite, $K_3Na(SO_4)_2$ (also known under its obsolete name aphthialite), and syngenite, $K_2Ca(SO_4)_2 \cdot H_2O$ (Charola and Lewin 1979; Barquin et al 1996; Bowler and Winter 1997). Mirabilite, $Na_2SO_4 \cdot 10H_2O$, and epsomite, $MgSO_4 \cdot 7H_2O$, are rare. Na-, K- and Mg-salts are readily removed by natural weathering, but syngenite, $K_2Ca(SO_4)_2 \cdot H_2O$, and gypsum, $CaSO_4 \cdot 2H_2O$, both types of deposits that frequently appeared during the last decades, can appear after more than one year after completion of the work and can be very persistent (Bowler and Winter 1997; Bowler and Winter 1996). The necessary sulphate may originate from several sources: brick, mortar, soil, air or rain. In brick, sulphates are formed during the firing process, and may remain present depending on the maximum temperature of firing. Na-, K-, and Mg-sulphates dissociate by firing above 950 °C, but Ca-sulphates may remain stable up to 1050 – 1200 °C, and may give rise to secondary formation of alkali sulphates by reactions of the type:

$$CaSO_4 + 2\ NaOH = Na_2SO_4 + Ca(OH)_2 \qquad (1)$$

In mortar, sulphate generally originates from the Ca-sulphate (gypsum, anhydrite, hemihydrate) added to control setting. If not added in surplus, this sulphate will be bound in monosulphate or ettringite during hydration. However, recent studies suggest that, depending on the availability of calcium carbonate, not all Ca-sulphate is bound as monosulphate or ettringite (Kuzel et al 1991), and may become available from decomposition of ettringite by carbonation (Kuzel 1996; Larbi 1998; Brocken et al 2000). Recent studies have also shown that surfactant phases like air entraining agents and other mortar additives may increase the mobility of Na, K, Mg, Ca and sulphate in bricks (Bowler and Winter 1997; Bowler and Sharp 1998).

Besides efflorescence of sulphates, efflorescence of Ca-carbonates, notably calcite, $CaCO_3$, often occurs on surfaces of masonry or concrete elements. In these cases, Ca-carbonate is secondary, due to carbonation of portlandite, $Ca(OH)_2$, formed by the hydration reaction of cement, or added as a binder component. White deposits of Ca-carbonate may occur as efflorescence or wash out after intensive wetting. Typically, it occurs on masonry consisting of bricks or blocks with low water absorption (Fig. 3), causing excessive wetting of mortar joints and simultaneously preventing carbonation of portlandite in the internal parts of the hardened mortar. As a result, $Ca(OH)_2$ will longer be available.

The Dutch standard on clay bricks only contains the initial soluble sulphate content as a parameter that may be used to get an indication of the potential risk of efflorescence NEN 2489 1976). Practical experience shows, however, that this parameter is not useful. With respect to efflorescence and wash out, there is a considerable amount of literature reporting experimental studies of lime deposits on massive concrete (e.g. Samuelson 1990). There are however limited experimental results available concerning lime deposits on masonry.

Figure 3. Efflorescence and wash out of lime occuring on masonry consisting of bricks or blocks with a low water absorption.

Though it has often been concluded that understanding relationships between pore structure and (potential) development of efflorescence is essential for understanding the process of efflorescence on porous materials (Barquin et al 1996), these relationships are still unsolved. Evidently, non-capillary macro-pores in porous materials facilitate the internal deposition of salts in these spaces, and, as a result, reduce the potential risk of efflorescence. Recent studies of the complex physico-chemical processes occurring in fresh mortar and the typical water transport characteristics between brick and fresh mortar or mortar joints (Groot 1993; Brocken et al 1998) and advanced non-destructive techniques to measure the corresponding water transfer such as NMR (Pel et al 1996) offer the opportunity to substantially improve the understanding of the efflorescence process on brick and concrete block masonry.

3 Genetic types of efflorescence

Based upon the detailed investigation of about 20 case studies in the Netherlands, several different genetic types of efflorescence could be identified, depending on the types of salt forming the efflorescence, the moment when efflorescence occurred, and the type of substrate material on which it occurred: (a) late efflorescence of gypsum on clay brick masonry, (b) early efflorescence of sulphates on clay brick masonry, (c) efflorescence / wash out of lime on masonry, (d) efflorescence of sulphates on concrete blocks, and (e) efflorescence of lime on (coloured) concrete (not considered here). The first four types will be described below. In all cases, a typical cavity wall construction was examined with an inside load bearing wall, insulation, air void and an outside brick or block masonry wall.

3.1 Efflorescence of gypsum on clay brick masonry

Efflorescence of gypsum occurs as a very thin, often semi-transparant, white foggy deposit on the surface of clay bricks (Fig. 2,4). It may also occur on the surface of the

mortar joints, but is hardly recognizable on this grey substrate. Typically in all cases investigated, this type of efflorescence appeared at considerable time after construction of the building, varying from some months to years, and gradually became more intense. This type of efflorescence is very persistent and hard to remove. In all investigated cases, only gypsum was identified as salt present in the efflorescence. Gypsum is only moderately soluble, explaining the persistent nature of this type of efflorescence.

Figure 4. Detail of figure 2.

3.2 Efflorescence of sulphates on clay brick masonry

Efflorescence of sulphates occurs often as an intense, white and fluffy deposit on the surface of clay bricks and sometimes also on mortar joints. In all investigated cases, it appeared already during construction of the buildings, before masonry units were pointed (Fig. 1,5). This demonstrates that pointing mortar does not provide any essential contribution to this type of efflorescence. Identification of minerals present in the efflorescence by X-ray diffraction showed that these were easily soluble alkali sulphates, notably thenardite, Na_2SO_4, syngenite, $K_2Ca(SO_4)_2$, and glaserite, $K_3Na(SO_4)_2$, occasionally accompanied by the lesser soluble gypsum, $CaSO_4{\cdot}2H_2O$. Consequently, this type of efflorescence appeared to wash off fairly well by natural rain.

3.3 Efflorescence / wash out of lime on masonry

Efflorescence and wash out of lime typically occurs on masonry consisting of bricks or blocks with a low water absorption (Fig. 3). During wetting, rain drops will run off from the brick surfaces and cause excessive wetting of the mortar joints. This facilitates dissolution of lime in the pore water of the mortar joints and prevents carbonation of this lime as CO_2 from the air can not penetrate into the saturated mortar structure. As a consequence, lime will be longer available in its soluble form. Investigation of the case studies has shown that the potential of efflorescence and wash out of lime is always existing, even if all possible precautions (protection from wetting) are taken during construction. In one particular case, the protection was taken away two weeks after the masonry façade was pointed. Unexpectedly, the next day it started to rain, resulting in a thin white wash out of lime from mortar joints over the bricks, even at such an age of the hardened mortar. In an early stage (before carbonation has occurred), this type of efflorescence and wash out of lime can be removed fairly simple with warm, steamy water. Moreover practical experience learns that a slight degree of lime deposits (and corresponding colour differences of pointing) disappear within a couple of years by natural weathering.

Figure 5. Detail of figure 1.

3.4 Efflorescence of sulphates on concrete blocks

In one of the case studies, efflorescence of sulphate was found on different shades of red, yellow and anthracite coloured concrete masonry blocks, whereas the non-coloured grey blocks representing the same mixture, without pigments, did not show efflorescence. This type of efflorescence was fluffy and washed off fairly well by natural rain.

Further microscopic analysis of the coloured blocks showed that ettringite was present in the air voids, except for the outer carbonated zone of blocks. This lead to the hypotheses that the absence of ettringite in the outer zone is due to its carbonation, resulting in an increase of the amount of soluble SO_4. The latter was confirmed by separate carbonation experiments on cement based materials (Brocken and Nijland, Construction and Building Materials, in press).

4 Substrate characteristics for early sulphate efflorescence

Apart from classification of efflorescence types and the possibility of cleaning, it is needed to estimate efflorescence risk (before as well as after cleaning) in relation to characteristics of the substrate material. In case of early efflorescence of sulphates on masonry, in all case studies the morphology of the efflorescing salts was identical for parts that were already pointed and parts that were not yet pointed. This does not exclude that components of efflorescing salts originate from the pointing mortar, but that these are apparently not essential and that composition of the pointing mortar is not a controlling factor.

4.1 Soluble contents

From investigated material samples obtained from the case studies the applied bricks appeared to have a higher content of soluble components than the non-applied bricks of the same type and specification. Further investigation of this phenomenon showed that in particular three parameters contribute to the amount of soluble components in applied bricks:

- the amount of soluble components in the non-applied brick,
- soluble components in the fresh mortar water that are taken up by the brick suction,
- the alkalinity of the fresh mortar water which can influence the amount of soluble components in the brick.

The influence of these three parameters is clearly illustrated in table 1, giving results of the analysis of soluble components in one specific brick type. Analysis of the non-applied brick are performed with water and 0.2M NaOH solution, showing a decrease in amount of soluble Ca and an increase in amount of soluble K and SO_4. Of course, a NaOH solution is not representative for fresh mortar water containing dissolved $Ca(OH)_2$, KOH and $CaSO_4$ as well, but the effect of alkalinity (not included in standardized test methods) is evident. In addition, table 1 presents soluble components determined in the same brick that has been in contact with a 10-12 mm thick layer of fresh mortar for about one hour. In general, both results indicate that the soluble components in applied bricks increase in comparison to non-applied bricks. Although these values represent data from single bricks (and should therefore be considered as indicative only), they illustrate that the amount of soluble components to be expected in applied bricks is more complex than the straightforward sum of amounts of these components in non-applied bricks and fresh mortar water. This highlights the role of interaction between brick and mortar and emphasizes the relevance of using masonry samples (in stead of bricks) for investigation and efflorescence testing.

Table 1 Investigation of soluble components in one specific type of brick according to the procedure described in NEN 2489 [10].

Soluble components Sample	Ca mmol l^{-1}	Na mmol l^{-1}	K mmol l^{-1}	Mg mmol l^{-1}	SO_4 mmol l^{-1}
Brick – analyzed with demi water	0.20	0.08	0.02	0.06	0.02
Brick – analyzed with 0.2M NaOH	0.10	-	0.16	0.00	0.46
Brick applied with mortar	1.07	0.15	0.07	0.01	0.12

4.2 Drying behaviour

Investigation of substrate material from case studies with early efflorescence of sulphates also showed that the respective bricks are characterized by moderate porosities (30-40 vol.%), moderate water absorption (Haller values 40-60 g/dm^2min) and uniform pore size distributions around 10 µm (Fig. 6). Accordingly, these bricks exhibit a good drying behaviour, i.e. relatively fast drying with hardly any delayed effects of moisture retained in smaller pores (more than 10-50 times smaller than 10 µm). Currently, the influence of drying behaviour is investigated in a qualitative manner by introduction of masonry types with various characteristics in efflorescence tests. If these tests indicate that drying behaviour is an important parameter, the respective material specifications will be investigated quantitatively.

4.3 Efflorescence test

For early sulphate efflorescence, a preliminary test method was developed that gives an adequate indication of efflorescence risk. First series of the test focused on analysis of appropriate wetting and drying conditions. Immersion of the substrates proved to be unsuitable because it allows leaching from soluble components from the substrate to the water in the reservoir. Saturation of samples by capillary water uptake is preferred. Subsequent to a saturation period, one dimensional drying is started under optimum conditions, i.e. increased air movement along the drying surface and a relative humidity of 50% or below.

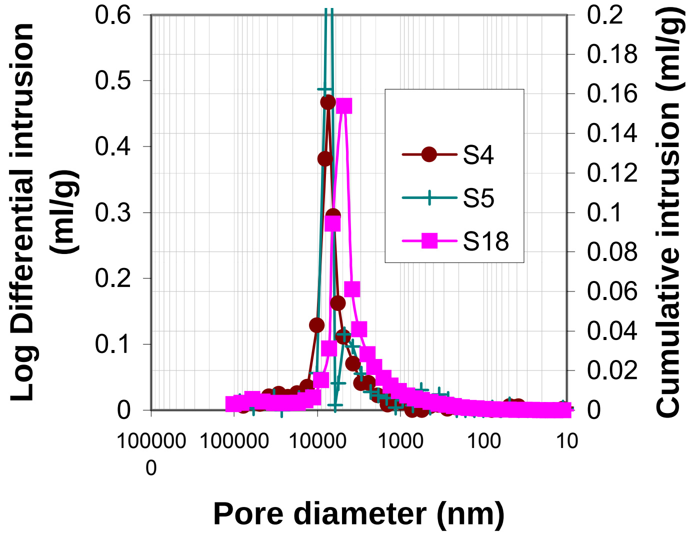

Figure 6. The typical uniform pore size distributions of bricks used in masonry with early efflorescence of alkaline sulphates.

Tests that have been performed until now proved to discriminate between efflorescence potential of masonry combinations. This is illustrated in figure 7 were masonry elements with three different brick types show decreasing amounts of efflorescence, corresponding to difference of efflorescence observed in practice. Furthermore, results until now showed that efflorescence risk is related to the amount of soluble components in the applied bricks: the more soluble components, the higher the risk.

Figure 7. Masonry elements with different brick types tested in the preliminary efflorescence test.

From these results, it can be concluded that the present test may be suitable for estimating efflorescence risk of masonry substrates. At present, research activities focus on further development of the test. First priority is to optimize the test with specific attention for:

- reproducibility & potential to discriminate between masonry substrates,
- fine tune wetting and drying conditions to relevant practical situations,
- develop an appropriate methodology to assess and qualify masonry substrates.

Meanwhile, the efflorescence test will be used to continue investigation of relevant material characteristics qualitatively. This may give indications for realistic solutions for early efflorescence of sulphates.

5 Efflorescence and wash out of lime

The investigated case studies confirm that efflorescence and wash out of lime occur predominantly after finishing pointing work of masonry consisting of bricks with a low water absorption. The latter contributes to an excessive wetting of joints. As a results of long wetting periods of the joints, penetration of carbonic acid from the air and corresponding carbonation (i.e. fixation) of lime (calcium hydroxide) to become limestone (calcium carbonate) are hindered. As a consequence lime remains longer available as soluble component. Considering this the risk of efflorescence and wash out of lime is strongly related to the porosity of the masonry materials, their moisture content and the rate of carbonation or other chemical binding reactions of lime.

Some commercial (pointing) mortars use trass or other puzzolanic additives to achieve hydraulic binding of lime. This method is suited to prevent efflorescence (and corresponding discolorations) on the long term. Though on the short term, within a period of weeks after application of the mortar, this positive effect is doubtful since hydraulic binding of lime takes considerable more time than cement hydration. The most pragmatic remedy for efflorescence and wash out of lime is to prevent hardening mortar from wetting, to start pointing work when masonry is wind dry, to prevent burning of the mortar, and to take care for appropriate follow-up treatment of pointing work.

Issues that are relevant for the efflorescence test for sulphates are generally also relevant for efflorescence of lime. In addition further research on efflorescence and was out of lime should focus on investigation of carbonation speed as a function of substrate porosity and moisture content and on hydraulic reactions of lime.

6 Future perspective

Based on the investigation of about 20 case studies in the Netherlands, several types of efflorescence have been identified, differing in mineralogical composition, type of substrate, age of appearance, etc. This demonstrates that white efflorescence on brick and concrete block masonry should not be considered as one single phenomenon, but as the result of one or more specific processes. Each type of efflorescence should be described by its own genetic model.

In collaboration with industrial partners, future research will focus on analysis of the causes and genetic mechanisms of the identified types of efflorescence, aiming at the development of a test for prediction of efflorescence risk of masonry. Additionally this test will be used for investigation of practicable solutions for efflorescence. The objective is to provide the masonry industry and its market with an appropriate method for efflorescence testing, corresponding product qualification (efflorescence potential in relation to envisaged use and building detail) and a facility to guide product improvement.

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