

Efflorescence **Mechanisms of Formation and Ways to Prevent**



Dr. Thomas Aberle
Elotex
Switzerland
thomas.aberle@elotex.com



Adrian Keller
Elotex
Switzerland
adrian.keller@elotex.com



Dr. Roger Zurbruggen
Elotex
Switzerland
roger.zurbruggen@elotex.com

Abstract: The unaesthetic discoloration of cementitious materials by efflorescence is a major issue in the dry mortar industry. The paper describes the phenomena in general with special focus on decorative mortars like renders. The mechanisms and influencing factors of efflorescence are well described in the literature. Most critical climatic conditions are low temperatures and high humidity. There are many different test procedures to simulate this. A special "double-chamber climate box" test was developed. Finally, the authors demonstrate efflorescence test results from renders modified with a newly developed anti-efflorescence product.

Keywords: efflorescence, mechanism, test methods, prevention.

1. INTRODUCTION

Efflorescence is caused by the precipitation of salts on the surface of mineralic building materials such as concrete, mortar or brick walls. It is a familiar problem in the construction industry and already widely described in the 19th century for masonry walls [1]. Nowadays, efflorescence is also a big issue of decorative mortars like renders and tile grouts.

Whilst efflorescence does generally not lead to significant failure, it mainly affects the aesthetic quality of the product (see Fig. 1). Often it appears within a short time after application, when worker, architect and owner are most concerned about the aesthetic

quality of the appearance of the new building. Especially in case of dark colored mortar surfaces the formation of bright spots causes an irregular pattern of high contrast.

Efflorescence mostly appears when porous construction material contain water soluble components, which are transported with the pore water to the surface. Upon evaporation of the transporting media the dissolved ingredients precipitate to form salt deposits on the surface.

Depending upon the circumstances, efflorescence can be more or less difficult to remove. Some treatments, such as the use of an acid wash, only have a temporary effect and the problem often reappears after a period of time.

The table below lists the most common types of efflorescence of mineralic building materials.

Table 1 - Chemical composition and source of efflorescence minerals. (Taken from [2]).

Composition	Source
Ca(OH)_2	Leachate from concrete and mortar.
$\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$	Alkali sulfates react with lime; SO_2 reacting with air to H_2SO_3 .
$\text{CaCl}_2 \cdot n \text{H}_2\text{O}$	If used as anti-freezing agent for concrete or mortar.
$\text{MgSO}_4 \cdot n \text{H}_2\text{O}$	If sea water is used as mixing water.
$\text{MgCl}_2 \cdot n \text{H}_2\text{O}$	If sea water is used as mixing water.
CaCO_3	Ca(OH)_2 reacting with atmospheric CO_2 .
KCl, NaCl	From de-icing salts.
$\text{Ca(NO}_3)_2 \cdot n \text{H}_2\text{O}$	If N-containing organic substances are decomposed and further react with Ca^{2+} .



Figure 1 - Cementitious render with efflorescence. (Photographed by J. Lang; Elotex)

Our work is focused on CaCO_3 formation, which is the most typical reason for efflorescence of decorative mortar surfaces like renders, tile grouts or top coats.

Whilst efflorescence is of main concern for decorative surfaces due to aesthetic reasons, the same principle of the formation of a thin crust of CaCO_3 , known as carbonation, can also occur in other types of mortars such as ceramic tile adhesives or self-levelling underlayments. If this carbonation reaction occurs very early, it can affect surface properties of the curing mortar and influence final scratch hardness or adhesion.

2. TYPICAL MECHANISM OF FORMATION

Efflorescence is generated when salts dissolve in the pore water and migrate to the surface where they precipitate. The pores must not completely be filled with water. Thin water films along the pore walls are enough to allow these reactions to occur (Fig. 2). In Portland cement based materials CaCO_3 is the most typical phase of efflorescence. Calcium hydroxide, a hydration product of Portland cement, dissolves in the water films along the pore walls forming Ca^{2+} and OH^- . Atmospheric CO_2 gas diffuses into the pores and is dissolved in the same water films, partly forming carbon acid (H_2CO_3). Carbonisation then takes place as a neutralisation reaction of calcium hydroxide and carbon acid, which forms the almost insoluble CaCO_3 (Fig. 2).

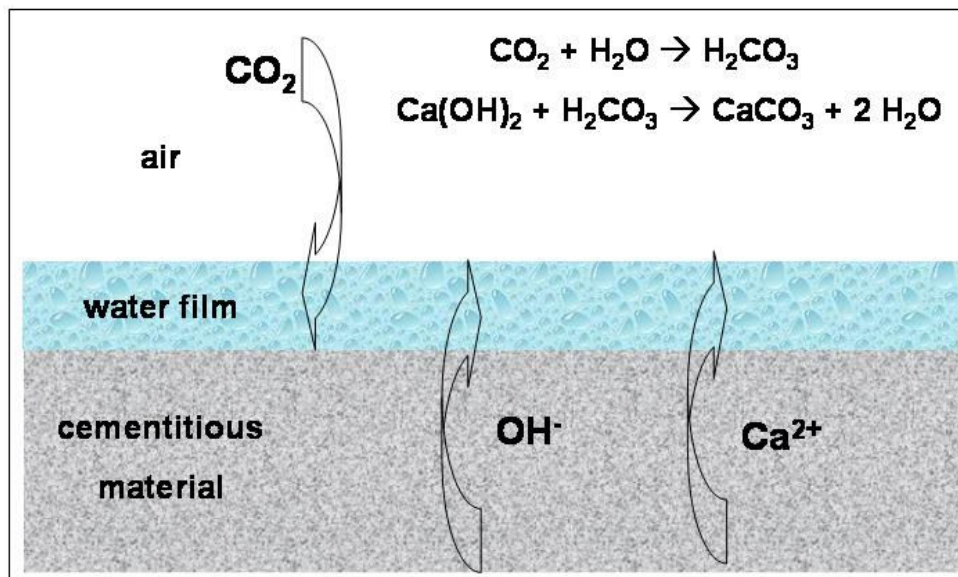


Figure 2 - Scheme for CaCO_3 formation in cementitious systems. (Taken from [3])

Efflorescence is particularly affected by temperature, humidity and wind. Usually, efflorescence is a seasonal problem [1] and appears mostly during winter time, when (i)

slower rates of water evaporation allow migration of salts to the surface and (ii) low outdoor temperatures cause condensation of water at the mortar surface.

In general [4], efflorescence is subdivided in two types, primary efflorescence and secondary efflorescence.

2.1 Primary Efflorescence

Primary efflorescence occurs days or weeks after application. Either excess of pore water from the mortar or severe curing conditions (like low temperature and high humidity) are the causes for the carbonation reaction described above (Fig. 2).

2.2 Secondary Efflorescence

Secondary efflorescence can occur years after application due to contact with water like in case of condensation of moisture or percolating water, e.g., when the mortar is subjected to cycles of drying and re-wetting. The reaction is the same as for primary efflorescence but the efflorescence pattern is often more heterogeneous than in case of primary efflorescence [4].

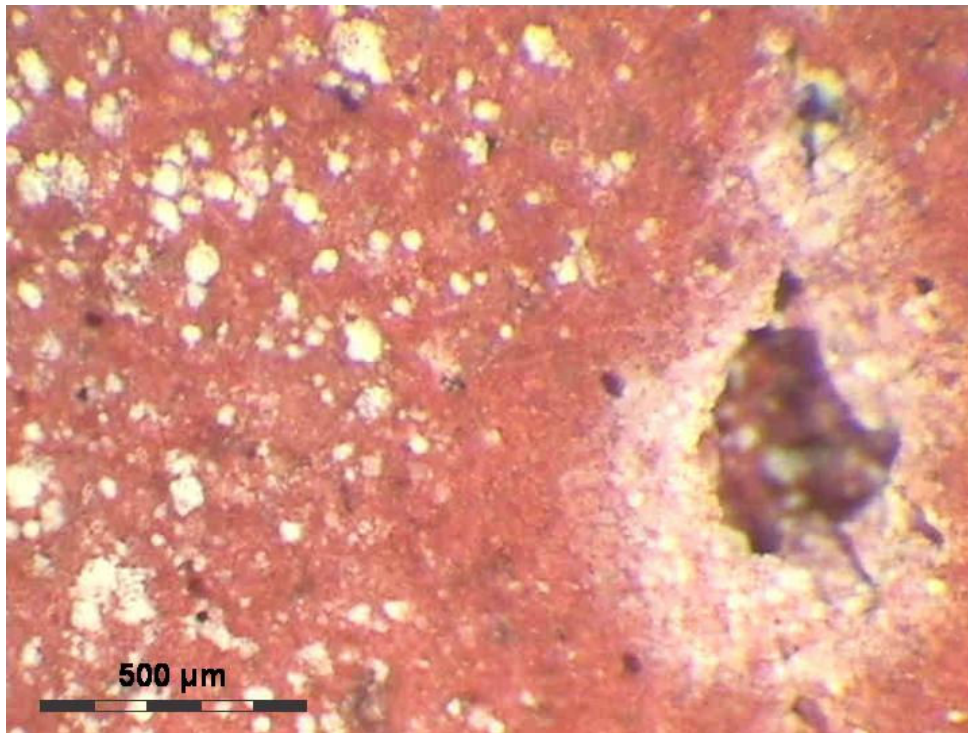


Figure 3 - Reflected light micrograph of the surface of a render with efflorescence of CaCO_3 . Note the massive deposit of CaCO_3 at the edge of the large air pore. There is an outer rim around the air pore, which is free of efflorescence. Further away from the large air pore (left side of picture) the efflorescence minerals form small aggregates ($< 100 \mu\text{m}$) sitting at the outlet of smaller pores.

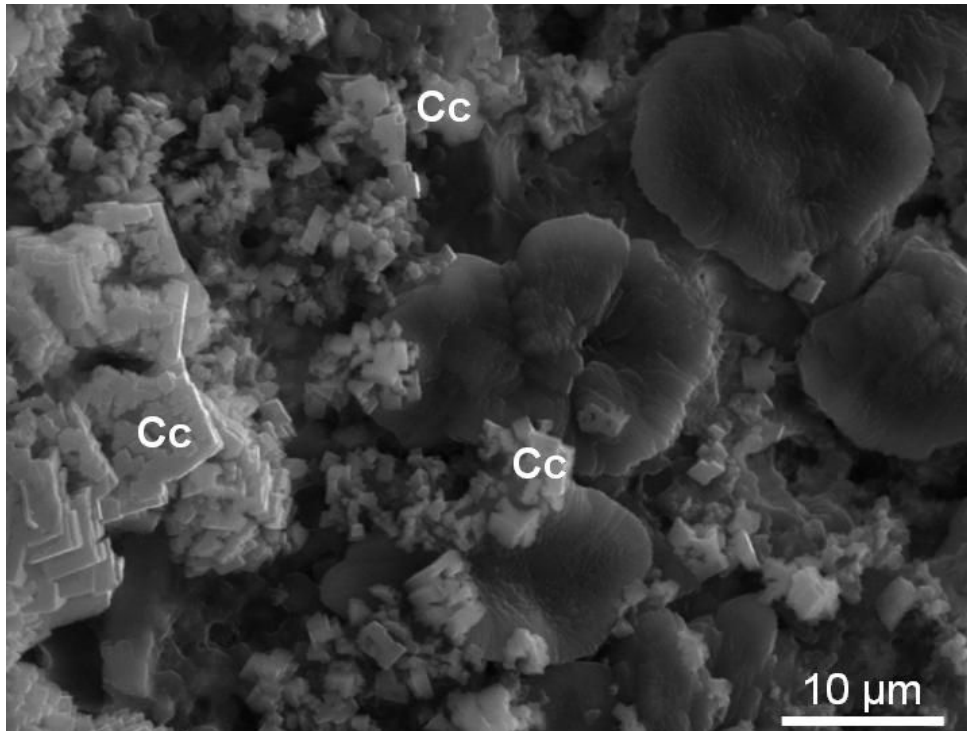


Figure 4 - Scanning electron micrograph (SEM) of a mortar surface with efflorescence. The rhomboedric morphology of the minerals is typical for calcite, the most common species of CaCO_3 (Cc).

3. LABORATORY TEST METHOD FOR EFFLORESCENCE

There are industrial standards for the testing of brick materials on their risk for efflorescence (ASTM C 67 or CSA A82.2). But no such standards exist for decorative mortars. This explains the great variety of efflorescence tests in the building industry. All of those tests which are known by the authors base on one of the three principles:

(1) The mortar surface is wetted (e.g., sprayed with water) and let to dry to mimic wetting from outside by rain, splashing water or condensation of fog. This procedure can be repeated in analogy to multiple wetting cycles in wet cells or outdoors.

(2) The lower part of the mortar sample is immersed into water [1] or laid on a wet sponge [5] to provoke capillary water to migrate through the porous mortar. As the pore water reaches the surface it evaporates and dissolved ingredients precipitate.

(3) The mortar sample is placed in a "double-chamber climate box". On both sides of the sample different climatic conditions (temperature and humidity) cause condensation, capillary flow and evaporation. The Elotex Laboratory Test for Efflorescence is based on this principle (see Fig. 5). By exposing freshly applied mortar samples this test allows to check for primary efflorescence behavior (for details see

chapter 4). As known from damage reports, low temperatures and high humidity during and after application are critical climatic conditions. Therefore, our laboratory test for efflorescence is done at such conditions.

4. RESULTS GAINED BY THE ELOTEX LABORATORY TEST FOR EFFLORESCENCE

For the test, dry mortar is mixed with water and applied on a porous tile, which is immediately placed on the test apparatus. Water of 20°C is circulated on bottom of the test apparatus, so that climatic conditions inside the apparatus are warm and humid. The test apparatus is placed in a climate chamber at 7°C and 80% relative humidity. By this procedure, the probability for the formation of efflorescence can be tested within a few days. The results are reproducible.

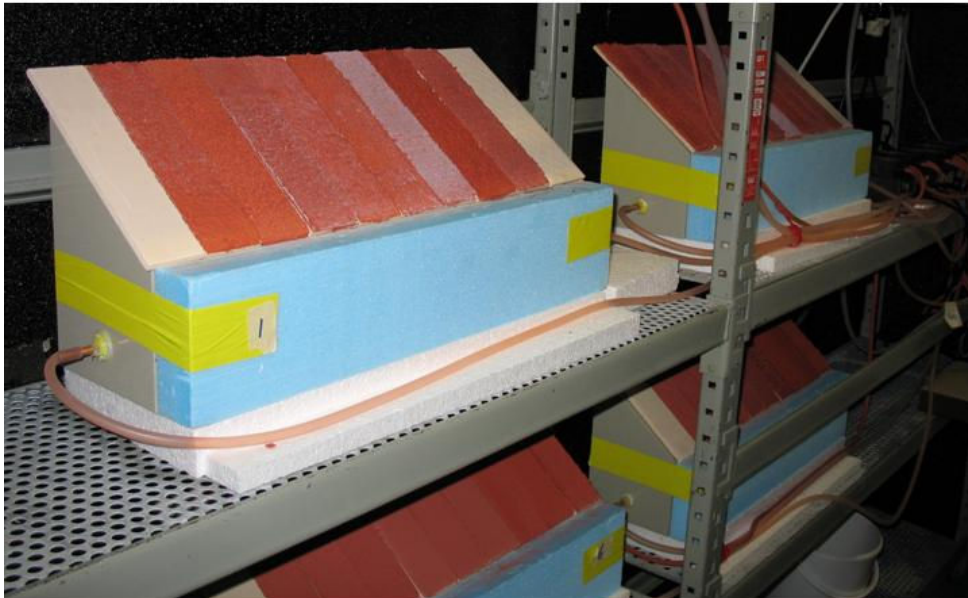


Figure 5 - Elotex test apparatus for the measurement of the probability for primary efflorescence. The picture displays four testing cells, each of which can be loaded with 10 samples.

Renders (for formulations see Table 2) were applied with 2 mm thickness on porous tiles and immediately placed on the test apparatus (Fig. 5). After 7 days the samples were inspected visually and by optical microscopy (Fig. 6). The reference mortar (render without additive) shows pronounced efflorescence. The render with 0.2% Elotex ERA100 shows no efflorescence.

Table 2 - Composition of render test formulation. Proportions are given by parts of dry mix **in weight %**.

Test formulation for a render	
White Portland cement	27.95
Quartz sand	70.00
Red Pigment	2.00
Cellulose ether	0.05
Water (<i>per 100 parts dry mix</i>)	18.00

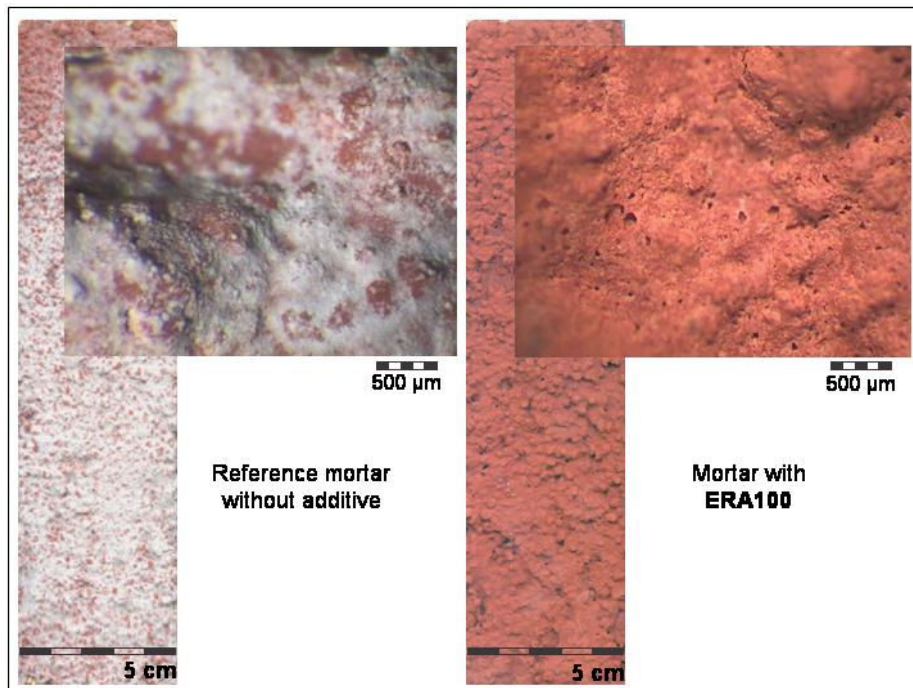


Figure 6 - Results according to the Elotex Laboratory Test for Efflorescence for render formulation without additive (left) and render formulation with 0.2% Elotex ERA100 (right).

5. EFFLORESCENCE – PREVENTION IS BETTER THAN CURE

As it takes much effort and time to get rid of residual salts of efflorescence, the best way is to prevent the formation of efflorescence. There are different concepts:

a) Seal surface

An expensive method to prevent efflorescence is to protect the product with a water impermeable coating. Beside the additional material costs, also an additional working step is required.

b) Mix binder system

Tricalciumsilicate (C_3S ; see abbreviation guide below) is the major clinker phase of Ordinary Portland cement. Because the Ca/Si-ratio of the Portland cement clinker is significantly higher than that of the calcium-silicate-hydrate phases (C-S-H) hydration of C_3S forms a substantial amount of $Ca(OH)_2$ (abbreviated in reaction 1 as CH). This excess of Ca in the form of $Ca(OH)_2$ is the major source for efflorescence in cementitious systems.



(Abbreviations of oxide nomenclature: C: CaO; S: SiO_2 ; \$: SO_3 ; H: H_2O ; A: Al_2O_3)

The approach of [5] tries to avoid the formation of $Ca(OH)_2$ by the formulation of a mixed-binder systems containing additional sources of calcium aluminate, calcium silicate, calcium sulphate and reactive silica in such proportions that, upon hydration ettringite is formed according to reaction 2.



However, elsewhere ettringite is reported as an efflorescence mineral [2].

c) Block capillary pores with micron-sized particles

Efflorescence can be reduced, by the incorporation of fine fillers which block the pores, examples being fumed silica, metakaolin or limestone fillers.

d) Add Ca^{2+} consumer

Another method for reducing efflorescence is to include reactive silica. The excess calcium hydroxide from the hydration of Portland cement (reaction 1) reacts with soluble silica (amorphous silica), namely natural puzzolana (e.g., Trass) or synthetic puzzolana (e.g., silica fume) to form further C-S-H (reaction 3).



e) Combined approach by special additives

The special dry powder additives Elotex ERA100 and Elotex ERASEAL120 can prevent occurrence of efflorescence in many of the cases. ERA acts by several physical and chemical mechanisms.

- Optimisation of capillary pore size.
- Reduction of capillary connectivity.
- Temporary reduction of Ca^{2+} concentration.

As described in [6] the permeability of a mortar is strongly dependent on the amount and degree of connectivity of mesocapillaries. The reduction of water uptake and a distinct shift in pore size distribution indicate that ERA is acting by optimisation of the pore size distribution. It is believed, that this effect is caused by the small particles a few μm in size which are formed after redispersion of the powder blocking capillary pores.

However, this is only one aspect of how ERA is acting. Further investigations have shown that ERA is also influencing the Ca ion concentration during a specific phase of primary curing, which supports the prevention of formation of efflorescence.

ERA100 and ERASEAL120 are dry powders and can be added to dry mix mortars. A further advantage is that they are already effective at low dosages (Fig. 6). The results can nicely be observed under the polarised light microscope (Fig. 7).

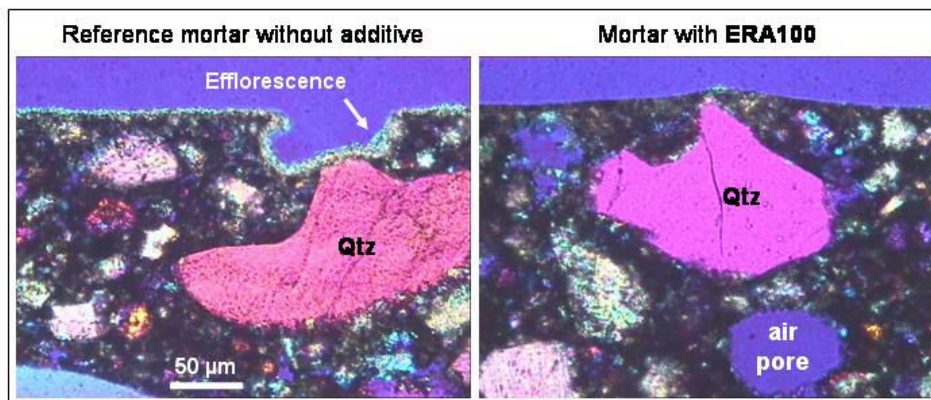


Figure 7 - Optical micrographs under polarised light (crossed nicols with compensator) of mortar surfaces. Left: Reference mortar with an approximately 10 μm thin crust of efflorescence minerals with a high birefringence colours typical for calcite. Right: Same mortar formulation modified with 0.2% ERA100. The mortar surface is free of efflorescence.

6. REFERENCES

- [1] Ritchie, T. *Efflorescence*.
(Link dato 26.9.06: http://irc.nrc-cnrc.gc.ca/pubs/cbd/cbd002_e.html) 1960.

[2] Henning, O. and Knöfel, D. *Baustoffchemie*. Verlag für Bauwesen, Berlin, 1997.

[3] Dow, C. and Glasser, F.P. *Calcium carbonate efflorescence on Portland cement and building materials*. Cement and Concrete Research, 33, 147-154, 2003.

[4] Bensted, J. (2000): Efflorescence - prevention is better than cure.
(Link dato 26.9.06: <http://www.resiblock.com/academics.htm>)

[5] Constantinou, A.G., Dow, C., Fentiman, C.H.R.H., Hoy, M.R., Scrivener, K.L., *Non-efflorescing cementitious bodies*. Patent Number WO 01/72658, 2001.

[6] Zurbriggen, R., Aberle, T., De Gasparo, A., Herwegh, M., *Additive optimieren Mörteloberflächen*. Farbe und Lack, 6, 45-51, 2007.