Evolution of Salt Efflorescence on Clinker Face Walls

To cite this article: Anna Kaczmarek 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 032036

Evolution of Salt Efflorescence on Clinker Face Walls

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Abstract. The lowering of building element aesthetics caused by salt efflorescences can have various characters. It depends mostly on types of wall component types, external environment conditions, and on-going physical and chemical processes. The active salts responsible for efflorescence appearance do not only worsen the wall look. They can also lead to lower durability because of microstructure destruction both in ceramic as well as in mortar. The type of mortar used for face clinker walls in essential way influences the limitation of efflorescences and discolorations which appear. Additionally, the way how wall is formed on the subsoil is a factor determining the character of salts appearing. In this work there is an analysis of the evolution of efflorescences appearing on two exemplary face walls made with various mortars. The walls were built with solid clinker bricks of traditional size 250x120x65mm in connection with two mortars: cement mortar based on portland cement CEM I 42.5, and cement-lime one. Additionally, during the research three different contacts of the wall with subsoil were tested: gravel layer, humus with lawn, and tight concrete band. The analysis lasted for ten years of wall exploitation in external environment. In the tested walls there were made chemical analyses for the quality and quantity of the appearing salts. There is also a raster picture of appearing efflorescence evolution made with AutoCad program during the research time period.

1. Introduction

In present fast technology development there are new materials introduced to construction, and although their properties are known there is not necessary experience regarding their durability and resistance to influences of environmental impact for many years.

Facing walls in objects of small scale architecture are constantly influence by factors coming from surrounding environment. These factors, contributing to destruction of material structure, lower their usage durability. Taking into account complex and multi-component character of influences there are identified two basic groups of destructive factors. The first one, constituted by environment factors including chemical pollutant:

- atmospheric rainfall,
- splashing water,
- water floods (for example: water supply defects),
- ground humidity,
- snow cover.

The second group are internal factors which include properties of built-in materials and their mutual interactions. The result of these factors interaction are primary and secondary efflorescences, which evolution leads to surface and in-depth destruction of clinker wall units [1].

The above influences were described by exposition classes. They define factors directly influencing construction which in turn influence using proper wall elements, Table 1 wall materials systems (mortar, inserts), and thus structural protection of the wall.

Table 1. Classification of micro-conditions of exposure of completed masonry according to EN 1996-2 [1]

Class	Micro condition of the masonry	Examples of masonry in this condition
MX 3.1	Exposed to moisture to wetting and freeze/thaw cycling but not exposed to external sources of significant levels of sulphates or aggressive chemicals	Masonry exterior walls sheltered by overhanging eaves or coping, not exposed to severe driving rain or frost. Masonry below frost zone in well drained nonaggressive soil
MX 3.2	Exposed to severe wetting and freeze/thaw cycling but not exposed to external sources of significant levels of sulphates or aggressive chemicals	Masonry not exposed to frost or aggressive chemicals, located: in exterior walls with capping or flush eaves; in parapets; in freestanding walls; in the ground; under water
MX 4	Exposed to saturated salt air, seawater or de-icing salts	Masonry in coastal area. Masonry adjacent to roads that are salted during the winter.
MX 5	In an aggressive chemical environment	Masonry in contact with natural soils or filled ground or groundwater, where moisture and significant levels of sulphates are present. Masonry in contact with highly acidic soils, contaminated ground or groundwater. Masonry near industrial areas where aggressive chemicals are airborne.

In numerous scientific publications there are introduced research methods performed on real construction objects where salt efflorescences were localized [3,4]. The proposed methods of research HMC (hygroscopic moisture content) are directed on setting the wall salinity rate.

Lubelliet al. [5]in use the HMC method in order to state the salt presence in walls. However, the negative feature of this method is that it enables to define only one type of salt. In case of mixture of salts, the research result is not concrete, because it gives only possibility to diagnose the presence of the substance without quantity and quality analysis.

In the latest years we can observe significant interest in numerical research of mineral salts transportation in porous materials [6,7]. The mathematical models created and results obtained in experimental tests in significant ways contributed to developing computer programs modelling influence of salt crystallization process on construction material strength, and in consequence on durability of facing walls [8].

The aim of this work is the quality and quantity analyses of salts crystallized on face walls. For tests there were selected test walls made of solid clinker bricks connected with two mortars: CEM I based on portland cement and cement-lime one. Additionally, in evaluation there were considered three options of wall contact with subsoil i.e. tight concrete band, humus with lawn and gravel filter layer. The tests include hanges of efflorescence occurring after ten years of wall exploitation in external environment comparing discolorations from the first year of wall functioning.

2. Efflorescence

Definition of efflorescence met in bibliography [1] is formulated as: crystal salt extracting from saturated salt solution, on surface of a material does not reflect fully the phenomenon. Besides salt, in the wall there are compounds originating from mortars (mostly $Ca(OH)_2$), or from improperly protected steel inserts. In presence of water they are solved and transported on surface where they lower wall aesthetics, and under influence of compounds coming from outer environment undergo further changes [2,3].

Depending on source of humidity on ceramic can be visible efflorescence [3]:
- primary, created as a result of migration of chemical compounds from ceramic material and fresh mortar, associated with drying of technological moisture,
- secondary, created as a result of wall penetration by rainwater or condensation.

Resulted efflorescence can take a form of:
- deposit (some amount of salt crystallized in sub-surface layer, causing colouring of ceramic material [Figure 1a]),
- sediment (salt layers crystallized evenly on surface of ceramic material [Figure1b]),
- infiltration (layer of salt gathered in cracks and slots, where water migrates on surface of ceramic material [Figure 1c]).

Figure 1. Efflorescence types: a) deposit, b) sediment, c) infiltration

3. Material and experiments

3.1. *The field test-stand*

The field test stand for was located in the University of Technology and Life Sciences in Bydgoszcz (Poland). The complete test-stand covers eight test walls, one brick thick, of dimensions 1.61 m x 1.42 m, made with standard bond. The wall gables face the wind direction identified for the area according to the reports of the Regional Inspectorate for Environmental Protection in Bydgoszcz, Figure 2. Three walls constructed in a system with the following mortars were used in analysing the impact of long-term exposure to atmospheric factors (Table 2):

- Cement mortar, based on Portland cement CEM I 42.5;
- Cement-lime mortar based on Portland cement CEM I and hydrated lime CL90, which does not form soluble mineral salts at bonding.

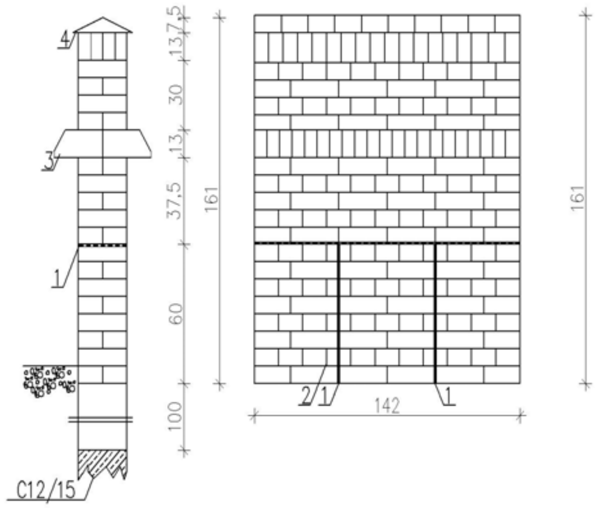

Figure 2. Test wall for field research 1 – insulating tarpaper underlay, 2 – 1/2W fitting, 3 – 1K fitting, 4 – DD fitting

Three options for the wall contact with the ground surface were modelled in the test-stand, Figure 3:

- Humus with lawn;
- Gravel filtration layer;
- Tight concrete belt.

To evaluate the impact of the direct wall contact with the substrate, three areas typical for the migration of soluble mineral compounds forming efflorescence were identified

- Wall contact with the adjusting humus layer;
- Wall contact with the tight concrete belt;
- Wall contact with the gravel filtration layer.

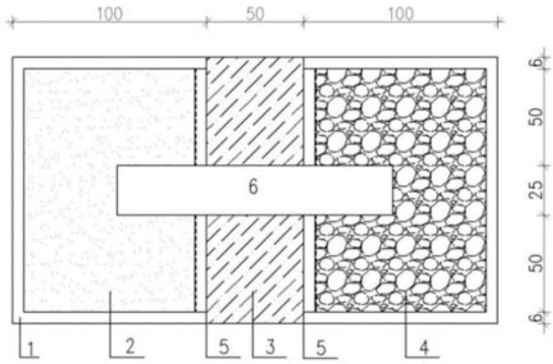

Figure 3. Test wall for field tests 1) underfelt - insulation separating the analysed areas, 2) clinker semi-fitting, 3) clinker fitting with a single-side edge bevelling, 4) clinker roof, 5) concrete moulding, 6) foundation

Table 2. Composition of tested mortars

		Contents of 1 m^3			
Mortar	Proportion of components	Cement [kg]	Lime [kg]	Sand [dm^3]	Water [dm^3]
CEM I	(c:s) 1:3.5	378 CEM I 42.5N	-	1.05	0.253
C-L	(c:l:s)1:1.25:6.75	165 CEM I 42.5N	97	0.95	0.304

The distinguished areas are separate fragments of the wall, separated with a layer of vertical, tight insulation made of asphalt underfelt. The solution prevents the migration of moisture and salt from the adjacent surface. Insulation protecting against moisture was used in the designed wall at the following two levels:

- Foundation wall (10 cm below ground level);
- 50 cm above the ground level.

The insulation was intended to protect against water migration from the foundation concrete (level 1) as well as to separate the area exposed to splashed water (level 2) in different options of contact with the ground. When the substrate was hardened (concrete belt), the splashed water reach was 50 cm. For a rough surface that strongly dispersed precipitation water (loose gravel pack, humus with lawn), the height of activity was reduced to approx. 20 cm. In winter, the walls were exposed to snow. The reach of this hazard depends on the snow-cover thickness which, in the analysed location, did not exceed 50 cm. The walls were observed for three years, in three-month intervals, at least seven days after any rainless period. The inspection activities also included the regular taking of photos of the entirety of each wall and three areas of contact with the surface of the ground. The size of the areas covered with efflorescence was determined based on the analysis of a raster image in AutoCad. The surfaces covered with efflorescence were established by separating the joint and the facing surface of the ceramics.

3.2. Chemical test

After making an inventory of the walls, samples of efflorescence were collected for chemical tests. The formed deposit was thoroughly removed by scratching the facing surface of the ceramics, keeping it intact. Samples prepared this way were used for the qualitative and quantitative analysis of water-soluble salts. To conduct the test, the efflorescence samples were ground into a mortar, sieved through a screen with mesh size of 0.1 mm and dried to a constant weight. Added to measurement beakers with a volume of 100 cm^3, approx. 1 g of material was measured on analytical scales (with an accuracy of up to 0.0001 g) and poured in distilled water at a ratio of 1:50. The samples were tested and left for 24 hours under normal conditions. The suspensions were filtrated to 100cm^3 measurement flasks. The obtained solution was used for qualitative and quantitative analysis and for the identification of soluble salts in the efflorescence.

A part of the obtained solution was placed in 20 cm^3 measurement beakers and, with the use of a microcomputer conductivity measurement device, specific conductivity was measured with an electrolytic-resistance sensor, expressed in millisiemens per cm [mS/cm]. This formed the basis for calculating the percentage quantity of ions in the solution as compared to the weighed amount.

The remaining quantity of the prepared solution was evaporated to 1cm^3 volume and then subject to microcrystaloscopic qualitative analysis. The obtained results allowed for the identification of soluble salts in the material samples.

4. Results and discussions

4.1. Evaluation of the face wall contact with tight concrete band (Table 3)

On the test face wall built with CEM I concrete mortar during the first year of exploitation there were not visible primary efflorescence. Both on ceramic and mortar surfaces the share of efflorescence was 0%. After 10 years on clinker and mortar surfaces there were appearing secondary efflorescences (6.9%). In the wall built with cement-lime mortar on surface of bricks and mortar there were primary efflorescences. They covered totally about 11% of the tested area. After 10 years of exploitation the share of crystallized salt layers decreased to the level of 3.7%.

Table 3. Evolution of efflorescence in the subsequent years of use - wall contact with the adjacent concrete belt

Area with efflorescence		Wall contact with the adjacent concrete belt	
		Cement 1	Cement-lime
Brick face [cm2]	1year	0.00	255.90
	10 years	146.20	80.40
Mortar [cm2]	1year	0.00	18.30
	10 years	22.30	10.30
Total [%]	1year	0.00	11.20
	10 years	6.90	3.70
Analysed area [cm2]		52 cm x 47 cm = 2444.00 cm^2	

4.2. Evaluation of the face wall contact with humus layer (Table 4)

After analysis it was found that the contact of the face wall with humus layer was the most susceptible to appearance of efflorescence and discoloration. The wall orientation according to geographic directions let us state that this is the area most susceptible to driving rain and prevailing wind directions. Influence of these factors creates area of constant moisturizing. It is a favorable situation for migration of salts responsible for appearance of efflorescence. During the first year of exploitation on the wall built with CEM I cement mortar there was observed a significant share of primary efflorescence comparing to the overall surface (19.35%). After 10 years the share of efflorescence stayed at similar level. The secondary efflorescence covers about 21% of the tested area. The results for cement-lime mortar were different. After the first year of tests the area of primary efflorescence amounted to 23%. After 10 it decreased significantly to 5%. This may suggest that salts responsible for efflorescence appearance belong to a group of water-soluble salts and they were rinsed.

Table 4. Evolution of efflorescence in the subsequent years of use - wall contact with the adjacent humus layer

Area with efflorescence		Wall contact with the adjacent humus layer	
		Cement 1	Cement-lime
Brick face [cm2]	1year	256.87	557.26
	10 years	436.20	120.40
Mortar [cm2]	1year	216.01	0.00
	10 years	82.30	0.00
Total [%]	1year	19.35	22.80
	10 years	21.21	4.90
Analysed area [cm2]		52 cm x 47 cm = 2444.00 cm^2	

4.3. Evaluation of the face wall contact with gravel filter layer (Table 5)

During the analysis of the face wall contact with the gravel filter layer it can be stated that CEM I concrete mortar is characterized with susceptibility to primary efflorescence (19% of the area). After 10 years of exploitation in external environment the secondary efflorescence covered 4% of the tested area. The cement-lime mortar shows a significant decrease of efflorescence appearance from 22.8% to 5.9%. The gravel filter layer allows for limiting the influence of splash water and cut off the lateral humidity movement.

Table 5. Evolution of efflorescence in the subsequent years of use - wall contact with the adjacent gravel filtration layer

Area with efflorescence		Wall contact with the adjacent gravel filtration layer	
		Cement 1	Cement-lime
Brick face [cm2]	1year	97.52	143.12
	10 years	133.20	220.40
Mortar [cm2]	1year	0.00	0.00
	10 years	82.30	12.40
Total [%]	1year	19.35	22.80
	10 years	3.99	5.90
Analysed area [cm2]		52 cm x 47 cm = 2444.00 cm^2	

4.4. Evolution of efflorescence chemical compound

During subsequent years of exploitation on surface of separated areas of test walls appeared efflorescences of various intensity and chemical compound. In this article there are presented detailed results for test walls in contact with adjacent concrete belt, Table 6,7.

Table 6. Quality analysis of soluble salts in water in samples of efflorescences taken from the test wall on cement mortar from area of contact with concrete belt.

Year	Qualitative analysis						
	SO_4^{2-}	CO_3^{2-}	Cl-	NO_3^{-}	Ca^{2+}	Na^{+}	Mg^{2+}
Year 1	++++	-	-	śl.	+	+	-
Years 10	trace	++	-	-	-	trace	-

Acquired marking of the contact of salt ions:
+++ over 60%, ++ 30-60%, + 10-30%, trace less than 10%, - none

As the first example serves the wall built on CEM 1 cement mortar in which the amount of mineral water-soluble salts after 10 years of functioning goes down from the level of 51,55% to 14,30%. In the first year of functioning there were found high amounts of sulfates ($CaSO_4$, Na_2SO_4) and trace amounts of nitrates. There was not found the presence of chlorides and carbonates. After 10 years of exploitation the share of sulfates decreased at the expense of carbonates. The increased amount of carbonates indicates the ongoing destruction of mortar.

Table 7. Quality analysis of soluble salts in water in samples of efflorescences taken from the test wall on cement-lime mortar from area of contact with concrete belt.

Year	Qualitative analysis						
	SO_4^{2-}	CO_3^{2-}	Cl-	NO_3^{-}	Ca^{2+}	Na^{+}	Mg^{2+}
Year 1	++	-	-	trace	+	+	-
Years 10	++	-	-	-	trace	+	-

Acquired marking of the contact of salt ions:
+++ over 60%, ++ 30-60%, + 10-30%, trace less than 10%, - none

The wall made with cement-lime mortar was characterized in the first season with low share of water-soluble salts at 8,78%, with advantage of sulphates and trace amounts of nitrates. After 10 years with increased share of water-soluble mineral salts (to 19,90%), it was found that the high level of sulphate persists and there were appearing trace amounts of carbonates.

In the analyzed test walls the water-soluble mineral salts belong to sulphates (of calcium and natrium) and carbonates and nitrates (of calcium and natrium), which are characterized with high solubility.

5. Conclusions

On surfaces of the test wall analyzed there were found destructive damages in many places caused mainly as a result of excessive salinity occurring most often as salt efflorescence. Based on performed observation it was found that efflorescence intensity depends on year seasons and humidity conditions. The moisture in material structure because of capillarity enters dry parts of the wall and results in it damage through crystallization of salts and action of temperature differences. Additionally, moisture is introduced into the wall by actions of salts present in the wall. Hygroscopic salts stay in the wall after water evaporation continually absorbing moisture from the environment, according to mass exchange principle these solutions always transfer in the direction of the higher temperature. In subsurface wall layers' water evaporates thus the condensation of migrating salts increases until saturation and

oversaturation state. As a result, the salts crystallize which is usually accompanied with increase in volume (creation of hydrates), which in turn contributes to destruction of wall elements.
The evolution of efflorescence in subsequent years of field test wall functioning proved essential changes of quantity in deposits, sediments and dripstones on the face side of test walls in relation to various types of contact with ground surface. The contact zone of the wall with adjacent humus layer proved to be the most unfavourable place – efflorescences persisted through the entire exploitation period. In case of the contact of face wall with concrete band it was noticed primary efflorescence in area endangered with splash water. The gravel filter layer is a solution that minimizes appearance of efflorescence.

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