Protection against Degradation of Contemporary Face Walls

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Abstract. The face wall is a construction element which is exploited in difficult environmental conditions. Its material solutions should effectively protect it against environment influences. But often the desired effect is not obtained – on most objects there is efflorescence along with damages appearing with various intensity, as a result of corrosion processes. Their dynamics depends on various factors. The most important ones include the environment quality and wall structural integrity. In case of face walls, the basic environmental factors are driving rain, long term snow cover, and changing temperatures oscillating about the level of 0 °C. The structural integrity of the wall depends mainly on mortar which aside from obvious supporting function should also protect against water penetration into the wall and thus creating subflorescence. The article systematizes activities related to ensuring correct moisture conditions of the wall and its maintenance in a proper technical state during exploitation.

1. Introduction

The correct approach to renovation of face walls needs understanding of the salt crystallization mechanism. Efflorescence occurs when the following conditions are fulfilled:

- there is a source of soluble salts in water (mortar components, atmosphere, soil, metal and other elements built in the wall),
- water permeates into the wall, where the salts will be solved,
- there is a factor causing the salt movement (difference in condensation, temperature or pressure between wall interior and its surface).

![a) cement mortar](image1)
![b) cement-lime mortar](image2)
![c) system mortar with trass](image3)

Figure 1. Efflorescence concentration above snow cover level registered after the first winter season (field station for face wall test)
During the first years of exploitation, the so called primary efflorescences appear which are the effect of compound migration from fresh mortar, dissolved in technological water. They are most visible after the first winter. Their intensity depends on the period of building work execution, weather conditions during the construction erection and next months of functioning in a particular environment. The efflorescence distribution is conditioned by the architectural details used to protect against the rain water flow, solution of wall contact with ground and depth of snow cover (Figure 1). With properly adjusted mortars and strict technological regime, this primary efflorescence is solved during the next years until its complete disappearance. The research made by the author at the field test station indicates that the primary efflorescence period lasts for a minimum of 5 years. It also refers to the renovation work concerning mortar refilling and joint repair.

2. Primary efflorescence limiting

In order to limit the primary efflorescence, in mortars based on cement it is recommended to eliminate the start of alkaline reactions. It is advised to use low alkaline cements – containing below 0.6% of alkaline compounds (i.e. CEMI portland cements, CEMII/B-S portland composite cements, CEMIII blast furnace cements, CEMV composite cements). After final laying of mortar, the outer surface of clinker elements should be thoroughly cleaned.

The presence of hygroscopic water from mortar in pores is an important condition increasing carbonization. Without this water, the crystals of Ca(OH)$_2$ cannot dissolve and the carbonization process is stopped. On the other hand, when too many pores are filled with water there is no diffusion of CO$_2$. Besides the presence of CO$_2$ and Ca(OH)$_2$, the saturation by carbon dioxide depends on other parameters, for example the pore size in mortar and CO$_2$ permeability of these pores. In order to limit sulphate efflorescences, it is necessary to use HSR cement resistant to sulphates – according to the recommendation of Eurocode 6 [4]. This group includes cements: portland (CEM I), blast furnace (CEM III/A), pozzolanic (CEM IV). In ready-made wall mortars CEM I-SR0, portland cement is used (C$_3$A content in clinker cement = 0%), often with trass. This is a volcanic cinder from the basins of Rhine and Moselle with strong pozzolan properties (Table 1) that was used in the past by the Romans to add water-resistant properties to lime mortars. The addition of trass in contemporary mortars influences the range of their physical properties [9]. The most important include:

- high plasticity and porosity,
- unusual durability,
- high adhesion to the base and nearly five time less contraction than cement-lime mortars,
- resistance to water and aggressive environment influences,
- binding of calcium hydroxide - Ca(OH)$_2$ – which protects against calcium efflorescences.

The decisive is the reaction between SiO$_2$ and Ca(OH)$_2$. The soluble Ca(OH)$_2$ transforms into non-soluble silicate thus the main reason of primary efflorescence is removed.

\[
3\text{Ca(OH)}_2 + 2\text{SiO}_2 + \text{H}_2\text{O} \rightarrow 3\text{CaO} \cdot 2\text{SiO}_2 \cdot \text{H}_2\text{O}
\]
Crystals of calcium silicate make the mortar capillary structure much denser thus decreasing technological water transport from mortar to the facing wall.

**Table 1. Chemical content of trass.**

| Chemical compound      | Content [%] |
|------------------------|-------------|
| Silicon dioxide        | SiO₂        |
| Aluminium trioxide     | Al₂O₃       |
| Titanium dioxide       | TiO₂        |
| Iron trioxide          | Fe₂O₃       |
| Magnesium oxide        | MgO         |
| Manganese oxide        | Mn₂O₃       |
| Phosphor oxide         | P₂O₅        |
| Calcium oxide          | CaO         |
| Sulphur trioxide       | SO₃         |
| Potassium oxide        | K₂O         |
| Natrium oxide          | Na₂O        |

3. **Secondary efflorescence and subflorescence**

When the efflorescence transforms cyclically and additionally high moisture of the wall persists, it can be assumed that the wall protection against environment influence is insufficient. The crystallizing salts cause the destruction of the clinker surface layer (Figure 3). The moisture paths are created allowing the rain water to enter inside the wall causing destruction of mortar and clinker. At this stage, we do not consider the primary efflorescence, but it transforms into secondary efflorescence and subflorescence.

**Figure 3.** Example of a destructive result caused by soluble mineral salts in clinker (field test station for face walls)

Subflorescence is an especially harmful accumulation or multilayer of salt deposit under the surface of a wall resulting from moisture evaporation from the wall. It activates during freeze-thaw cycles when the mixture of moisture and salt freezes and expands creating internal pressure which, at a certain value, can split a wall part in external surface or cause its delamination [6].
Subflorescence should not be mistaken with secondary efflorescence which are deposits of soluble salts on wall surface. This efflorescence can be identified as a white colouration on the wall surface, dripstones or tarnishes. Efflorescence may be preceded by subflorescence, because it indicates the presence of salts.

Concerning the subflorescence creation mechanism, it can be stated that macroscopic identification of its occurring is possible with advanced degradation which is evident as:

- lenses and spots built of salt crystals,
- damage of face wall layer—the surface is aerated and can be easily removed with a sharp tool,
- peeling of layers (paints, hydrophobic surface), but also deposits of surface stain,
- capillary moisture in which salts can be solved and transported by water and next crystallized in particular wall zones. This is very well noticeable in zones affected by anti-freezing substances.

4. Maintenance of face walls

The maintenance of face walls at proper technical condition protects against water penetration and does not allow subflorescence to occur. Lack of casual conservation and protection of small damages is the most common reason for emergency states during exploitation which results in subflorescence.

During the first period of wall functioning, regular inspections must be made thus identifying possible damages of wall elements and joints. After minimum of 7 rainless days in April, there should be a proper date set for such an inspection. This is associated with salt properties, which are crystal substances easily soluble in water. Some of them, when hygroscopic, do not need liquid water, dissolve at a certain level of air humidity [12]. In case of direct exposition to environment conditions (air humidity, rainfall), it can be noticed that in winter months most of these salts function as liquid phase in the subsurface layer which is visible by darkening of joints (Figure 4).

In the period of primary efflorescence occurrence, the face wall should be regularly cleaned and its joints refilled. These actions needs to be repeated annually during the first five years in spring, possibly after salt deposits appear. All kinds of stain should be removed when elevation bricks are dry. The way of removing depends on their size. Small ones can be removed by a dry brush. In case of intense efflorescence in small areas, the method of physical desalination proves to be effective by utilizing so called ‘desalination compresses’, and they must remain on the stained area for a minimum of 24 hours.

When salinity area is large, wet cleaning can be used with chemical agents, but it is the ultimate step because such a treatment can lead to discolouration and damage of brick structure. The proper substances should not contain hydrochloric or nitric acid. The wall should be cleaned by narrow bands
from bottom to top, keeping the area below cleaning zone wet. Before the cleaning, the adjacent wall elements should be covered. On the selected band, the subsurface should be wet with water, next the cleaning substance should be applied with a nylon brush. The cleaning substance should be left on the surface for 10-15 minutes with periodical rinsing with water to avoid drying on the subsurface. Next, it should be cleaned with water under pressure. These substances often contain surface active additions which moisten surface and enable penetration into subsurface. In connection with a stream of water, they produce foam which allows to control removal of the substance from the wall – cleaning should continue until the foam disappears. After cleaning the entire area, the subsurface should be flushed again starting from the top. Cleaning can be intensified by using hot water. The optimum temperature of the wall surface should be from +20 to +25°C. Technical manuals allow a wider range of temperatures. However, in lower temperatures these substances are less active while in higher temperatures it is difficult to keep subsurface wet which is a requirement for such substances.

5. Repair work for face walls covered with subflorescence

Secondary efflorescence or subflorescence are unambiguous information that wall protection against humidity was damaged (or incorrectly performed). In order to identify the reason of humidity, it is essential to define the map of humidity on the elevation. For introductory diagnosis, a dielectric meter (based on measuring of the dielectric constant of surface layer for a material within the range of 3-7 cm) can be used [5]. Both for elevation bricks (for which water absorption is from 6% to 20%) as well for clinker bricks (for which water absorption is up to 6%), the humidity level should not exceed 3%. Local damps in copings, lintels and ledges are the effect of the loss of the wall integrity. The mortar is the main factor responsible for the wall integrity, and its main task is to provide cohesion in area of a joint of the wall elements [10]. This cohesion can be damaged because of errors in:

- design – lack of prevention against damage in places where strains concentrate, not taking into account thermal strains; assumption of the same width of foundation for all walls; wrong recognition of ground subsurface; incorrect design of new buildings settled on other level than adjacent buildings [3];
- technology – untidy laying of wall elements, not filled joints or joints too thick, deviation from the vertical line, using defective wall elements, incorrect masonry bond, too early grouting of joints, defective joints, not protecting the wall during and after construction work.

Description of wall construction repair was discussed in detail by many constructors [6]. The effect of technological errors is migration of rain water into the internal structure of the wall. The shape of face wall decides its resistance to rain. In the technical literature of 19th century, there were recommendations for joint shape already. The correctly made joint allows rain water to flow on the face wall and prevents gathering of snow and stains (Figure 5).

a) Correct profile of joints and grouts

![Correct profile of joints and grouts](image1)

b) Incorrect profiles of joints and grouts

![Incorrect profiles of joints and grouts](image2)

Figure 5. Examples of joint and grout solutions in face wall [1], [10]
Capillary humidity can be the effect of unsuccessful or damaged anti-moisture insulation. In such a case during laboratory tests the humidity level must be defined along with an adequate method of drying. This should be understood as a set of technical and technological activities which cause permanent decreasing of wall’s humidity level which allows leading further construction or conservation work, and after its end ensures proper exploitation. The humidity condition of the wall is also associated with the applied solution of subsoil which is in contact with the face wall. Based on tests on the field station performed by the author, it was found that during 10 years of the face wall exploitation the lowest changes of clinker and mortar microstructure were visible in the contact area with a gravel band [11][12].

In face walls, it is equally important to restore both integrity and aesthetics. It is a set of related actions which can be divided into 5 stages.

Stage 1 – disinfection.

On damp walls, northern elevations or in greenery neighbourhood, there are conditions for development of microorganisms – algae, lichens, fungus, and bacteria. In case of biological corrosion, a biocidal measure has to be applied. It can be put on elevation by a brush or by spraying. After about 1 hour, it must be flushed with pressurized water.

Stage 2 – cleaning.

In removing efflorescence, old paint coatings and atmospheric stains, chemical method describe above should be used, but also mechanical or aggregated methods (mostly in cleaning bricks from deposits and paint coatings) can be utilized. The mechanical methods include:

- dry cleaning using abradant in pressurized air stream. It is a quick and efficient method, but it is difficult to obtain the uniform abrasive effect. Often with the layer of deposits, the face wall layers are also removed, and edges of wall details are violated.
- elevation rubbing – method developed by the Thomann-Hanry company, also called powdering. The method is so delicate that even partly degraded areas can be cleaned with this method. The powder can be used only once. The used powder and dust created during cleaning is caught by vacuum cleaners and rinsed with water.
- Method of whirling stream by Rotec – a dry granulate or abradant with water are whirled with water in a special turbine with jets, and the abrasive effect is produced at the adjacent side of the whirling movement.

Stage 3 – refilling the reclines on face wall surface.

Refilling the reclines in wall elements is performed only on face bricks. In case of clinker bricks, it is recommended to replace the damaged elements. At this stage, the wall continuity is restored. Depending on the way by which the face wall was built, the repair range varies: simultaneous building and grouting face brickwork only mortar losses in joints are refilled, in case of grouting before the cleaning of elevation, the present grout must be removed. After the cleaning, the new grout is made with proper shaping (Figure 4a).

Stage 4 – colouristic integration of face wall.

If repairs or clinker replacement cause discolouration of the elevation, there is a need to integrate colours by putting on a glazing paint. This includes laying a thin coating of silicone paint with minimum content of pigments and fillers so the brick facture is fully maintained, glaze does not peel, and retains resistant to environment conditions.

Stage 5 – hydrophobization of face wall and optional anti-graffiti layer.

The final stage is hydrophobization which protects wall against water entering into face wall interior. If walls do not contain water-soluble salts and possess efficient horizontal anti-humidity insulation, they can undergo the structural hydrophobization. This means introducing a hydrophobic substance at depth of about 5cm inside the wall. Such layer thickness ensures a durable protection of bricks against entering of rain water [2]. This is an effective protection against chemical factors, water freezing and actions of salts dissolved in water. Hydrophobic surface is intended to prevent entering of rain water. It can be done only on a dry wall. Necessary protection is reached after putting on the
solution twice (wet on wet). The effectiveness of hydrophobic treatment is evaluated for about 7 years. After this period, the treatment should be repeated.

The anti-graffiti layer protects against spray paints, lacquers, markers and posters. After laying on the wall, these substances dry to transparency creating an invisible protective film, open for steam diffusion which prevents paints and lacquers to enter into subsurface. Solutions used can be divided into removable and permanent coatings. The removable coatings are made from substances based on wax. For removing of graffiti, a method of pressurized hot water (about 65-80 °C) is used. Under this temperature the coating puffs up and detaches. After cleaning, the removable layer should be laid again. In permanent coating solutions, two-component layers (2K) are used, which are resistant to paint removers which guarantees the possibility for quick and multiple cleaning without necessity of laying the layer again. In areas with a high danger of graffiti, hybrid coatings (permanent with temporary coating) are often used. It is necessary to pay attention that like hydrophobic ones, the anti-graffiti layers also undergo aging. After crossing the duration period, they lose their transparency and become visible (Figure 6).

![Figure 6. Aging of anti-graffiti coatings on facing walls](image)

6. Conclusion
The basic condition for a proper function of a face wall in external environment is the structural integrity throughout its entire period of usage. This structural integrity can be defined as the construction ability to retain bearing properties, functionality and shape within acceptable limits without occurrence of emergency conditions during exploitation. The wall integrity is mainly the effect of construction mortar which, besides its obvious bearing function, should also protect against water entering into the wall. The loss of structural integrity results not only in lowering aesthetics but also in leading to an emergency state of the face wall. Water entering the wall interior is the factor which ignites destructive processes. In planning the repair, the first action should be the wall inspection (elevation or an object) and in case of the necessity, an expertise which identifies sources of humidity and the level of efflorescence advance should be employed. Based on this information, a renovation plan should be developed which takes into account removing the humidity sources and construction reasons for breaching the wall integrity in the first place. Then, at the next stage, the work intended at restoring integrity and aesthetics of the facing wall should be done.

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