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Earth plaster as a means of salt reduction in historical brick and natural stone masonry – Principles, mechanisms and experience

All forms of solid historical structures – whether natural stone or brick masonry – are typically subject to the problem of rising damp and the concomitant crystallisation of soluble salts it transports. Some buildings are particularly susceptible, for example former stable buildings that are contaminated with nitrates leaching from animal faeces. Nitrates are the most critical group of harmful salts, which also includes sulphates and chlorides, as they are more readily soluble and can therefore rise to higher wall areas. Even slight fluctuations in air humidity can cause a change of aggregate state from solid to liquid and vice versa. When salts crystallise, they increase in volume. When this occurs within the pores of a material, it loosens the structure from within, causing it to disintegrate at the surface in particular. Depending on the pore structure, firmness and evaporation capacity of the materials, this can affect the bricks, the mortar or both.

Historical earth buildings frequently contain organic additives in the earth blocks, cob or rammed earth. When these are exposed to increased moisture over a sustained period, the organic components humify causing the building element to lose strength over its entire thickness. The result: the affected area must be replaced entirely. Purely mineral earth building structures, on the other hand, can withstand prolonged exposure to moisture. In such cases, and where earth walls with an organic component are only temporarily subject to moisture penetration, the wall core can often be preserved. After desalination treatment with a sacrificial plaster, damaged sections can then be repaired with new earth block masonry.

It is a common misconception that stone buildings are less affected by salts because stone itself is not capillary conductive. However, the mortar in which the stone is set can transport a considerable amount of moisture and soluble salts due to its higher capillary conductivity, particularly in the centre of the wall where there is typically a greater proportion of mortar.

Without suitable restoration measures, it is not possible to produce good wall finishes for salt-damaged walls that remain intact in the long-term. So-called

01 Former stable building with clear indications of moisture and salt load on the brickwork

02 Restoration plaster after a service life of 10 years without installation of a horizontal barrier

04 Even after installing a horizontal damp proof course, damage can still occur if no salt reduction measures are undertaken

03a and b The “restoration” of a basement using barrier plaster without installation of a horizontal barrier. 5 years on, the evaporation zone has shifted upwards and the coating has burst open.

restoration plasters merely delay the recurrence of dampness and salt contamination problems. Depending on the specific conditions of the building, these products buffer salts in their pore cavities for the short to medium term – typically 3 to 10 years – before the surface effects of salt contamination recur.

Barrier coatings only displace the moisture horizon, causing damp to rise higher in the wall, in turn increasing the extent of damage.

The only effective long-term means of rehabilitating wall cross-sections subject to rising damp and salt loads is a combination of the following measures:

1. Installation of a permanent, effective horizontal damp proof course, where necessary with additional vertical barrier layers, and
2. Reduction of salt levels in the damaged areas of the existing walls to a harmless level.

In our experience, chemical horizontal barriers should only be considered if it is not possible to install a mechanical damp proof course, for example for reasons of geometry or construction.

Similarly, if salt reduction is omitted, it is highly probable that salt damage to the surfaces will recur again despite the installation of a horizontal barrier.

All mineral building materials contain a level of salts, even directly after production, and this can rise with many years of service life and use. The German WTA bulletin 4-5-99/D Mauerwerksdiagnostik/Evaluation of masonry (WTA, 1999) defines the level of salt content above which an evaluation and possible remedial measures should be carried out for wall cross-sections that are to be plastered or rendered:

- Chlorides ≥ 0.20% by mass,
- Nitrates ≥ 0.10% by mass, and
- Sulphates ≥ 0.50% by mass.

05 Installation of a mechanical horizontal barrier using the wall sawing method as a preparatory measure for desalination

Slightly higher values can be tolerated for unplastered walls than for walls that are to be plastered, however, these are not precisely defined, and the limits given should therefore always be used as a guideline.

With experience, one can assess the level and distribution of potentially destructive salts within a wall based on certain visual characteristics. Nevertheless, it is still advisable to take samples at different heights and depths to acquire an accurate assessment as a basis for determining the extent and duration of salt reduction measures. The WTA bulletin on evaluating masonry provides a good basis for an analytical survey.

Salt reduction mechanisms

Salt reduction agents work as follows: the surface of the existing wall is moistened by lightly pre-wetting it and through the mixing water content of the salt reduction mass. This causes potentially destructive salts within the structure to dissolve so that they can be transported by capillary action. The duration of this moisture gradient from the salt reduction mass (moist) to the centre of the wall cross-section (less moist) should not be too short, but also not too long. If the wetting effect is over too soon, the salts are not adequately dissolved. If the wall is susceptible to drying out too quickly, the drying process can be retarded by applying a foil or damp cloths, but not for longer than one day. Excessive wetting or prolonged wetting on the other hand can cause moisture and the soluble salts within it to be temporarily transported deeper into the wall. This can lead to renewed salt occurrence on the wall surface at a later point in time.

As the wall structure dries, the capillary-active pore space of the salt reduction mass draws the soluble salts into the sacrificial layer. Depending on the salt reduction material, the temperature and the ambient humidity, this transport process can take between 7 and 14 days. Depending on the type of salt reduction material used, areas with a strong uptake of salts in the sacrificial layer can be visible as

- damp areas that do not dry due to the hygroscopic (water-binding) properties of the salts, or
- whitish surface efflorescence.

Both characteristics are particularly apparent when using traditional earth plasters due to the darker brown colour of the plaster. In areas where salt ingress is particularly evident, the salt concentration of the base wall may still be significant, and the process should be repeated accordingly.

The cycle of desalination should be repeated until the residual salt content is below the limit values given above. In areas with low salt loads, one or two desalination cycles may be sufficient, in medium to high

06a and b Salt penetration into the sacrificial plaster can be seen as whitish salt deposits on the surface or dark areas that do not dry out. Depending on the type and combination of materials in the existing structure, the salt concentration may be higher in the masonry mortar (left) or in the bricks (right).

load areas, three to four, in extreme cases five cycles may be necessary. The time these necessitate must be taken into account in the planning of the construction schedule. If none of the visual indications arise, the residual salt content in the underlying wall is, in the experience of the authors, below the salt content limit values. In some cases, this may obviate the need for an accompanying analysis.

Products for reducing salt concentrations

Various product groups are available for the reduction of salt concentrations in existing walls. The terms and products are defined in WTA bulletin 2-10-06/D Opferputze (Sacrificial plasters) (WTA, 2006).

For highly sensitive existing building fabric, for example where original paintwork must be preserved, the only suitable products are those that do not discolour and can be removed without mechanical means such as a hammer and chisel. In such cases, restorers use cellulose packs or flakes that are mixed with water and can be removed by peeling or brushing off with a light brush.

Other commercially available products consist of a mixture of clay minerals and cellulose flakes.

Lime-cement bound mixtures are also available on the market, to which porosifying agents or porous lightweight aggregates have been added.

Earth plasters can also be used directly as salt reduction or sacrificial plasters without any modification and represent a good alternative both in terms of their mode of use and price. As they need to be mechanically removed from the base wall and can cause slight discolouration to the existing surface, they are not suited for use on walls with historical paintwork or existing finishing plasters.

Compared with other salt reduction materials, current research (Voigt, 2017 and others) has shown that clay plasters are equally good or even better. A key advantage is the easy visibility of desalination progress. With a little experience, it is no longer necessary to employ analytical methods for monitoring successful desalination. Earth plaster is also cheaper for this application than other salt reduction materials.

As salt reduction plasters should be easy to remove from the base structure, earth plasters with a low strength class S I can be used, which are otherwise not permitted for permanent indoor use.

To be properly effective, the clay plaster itself must have a very low salt content. In Germany, the permissible salt content limits for clay plasters is given as follows in DIN 18947:2018-12:
- Chlorides $\leq$ 0.08% by mass,
- Nitrates $\leq$ 0.02% by mass, and
- Sulphates $\leq$ 0.10% by mass.

In addition, the total salt content must not exceed 0.12% by mass. The salt content of most earth plasters on the market in Germany is far below these limits. Care must be taken, however, in countries with arid climates, where salt-reducing plasters mixed from local earth and sand may not comply with these values.

The application of earth plasters for salt reduction

The process of using earth plasters for salt reduction is as follows:
- Installation of horizontal damp proofing and, if necessary, vertical barrier layers.
- Drying of the wall cross-section to transport a large part of the salts present in the cross-section of the wall to the surface. Depending on the moisture content and thickness of the existing wall, this can take several months. The installation of damp proofing barriers should therefore be carried out as early as possible, e.g. as an advance building measure.
- Delimitation of the extent of the area that needs desalination treatment by means of salt content analysis in the height and depth profile.
- Removal of existing plaster in the affected area unless required for historical conservation reasons.
- If the existing plaster is to be retained and is capable of preservation, any layers of paint and wallpaper must be removed.
- If the building fabric of the wall structure is already beginning to delaminate (peeling off in thin layers), all loose material should be scraped off vigorously with a mason's hammer.
- Joints should be scraped out at least 1 cm deep if the mortar is of low strength and therefore likely to contain salt deposits near the joint surfaces.
- The wall surface should be vigorously rubbed down to remove loose material using a hard broom.
- Careful cleaning of the surroundings, and disposal of any removed wall material.

- Repeated light spraying of the wall surfaces (pre-wetting).
- Application of the clay plaster at a thickness of 1.5 to 2.0 cm. Approximate levelling of the surface to ensure the minimum thickness has been applied across the entire surface, unless the application method already guarantees sufficient thickness across all parts of the wall. The service life of the plaster is 7 to 14 days depending on drying conditions.
- Note any still damp areas or areas of salt efflorescence, then knock off the plaster and sweep down. Wet and reapply further plaster in those areas still likely to have an excessive salt load.
- Once there are no further visual indications of remaining salt content at any point, the entire sacrificial plaster can be knocked off and the wall prepared for permanent plastering. If necessary, confirm that the residual salt content of the wall is sufficiently low by renewed sampling and testing.

Project examples

At ZRS we have been using earth sacrificial plasters as a means of salt reduction for around 15 years on projects at home and abroad. Most of these are historical brick buildings in Germany or historical stone buildings on the Arabian Peninsula.

Barn conversion Weesow, Brandenburg/Germany

A historical brick barn in Weesow, east of Berlin, was to be converted into a residential building. As the building has a listed brick façade, it was to receive interior insulation (architect: Jan Rösler Architekten, Berlin). ZRS Ingenieure GmbH were enlisted for the structural engineering and building physics. A survey and analysis of the condition of the existing building fabric, which dates back to the late 19th century, was undertaken to determine a basis for the further planning. A typical structural engineer's report usually focuses on structurally relevant damage (e.g. settlement, leaning, cracks), the condition of timber elements with respect to wood preservatives and pest infestation as well as dampness and salt damage. In most cases, these aspects are interrelated and best investigated by the same team.

The building structure exhibited high to very high levels of moisture and salt content in some areas due partly to its construction, age, lack of upkeep and not least its partial use for keeping livestock. In these areas, the nitrate values were up to six times higher than the recommended maximum values outlined by the WTA.

07a Barn in Weesow: View from outside showing clearly visible moisture and salt damage.

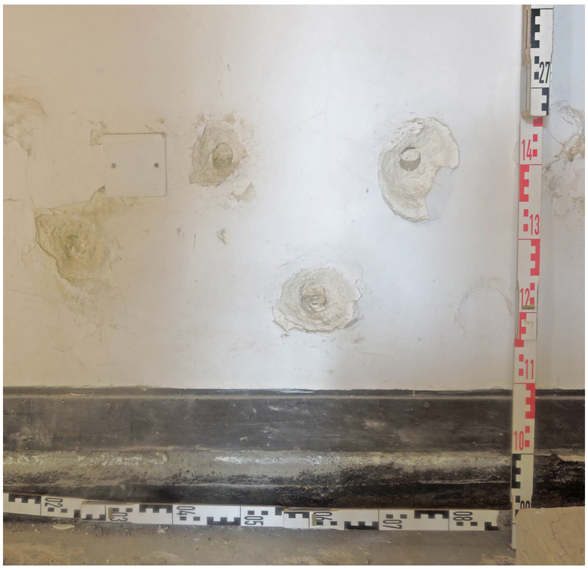
07b Barn in Weesow, D: Interior with areas of supercritical salt contamination marked

At relevant locations, a height and depth profile of the moisture and salt load was established by taking samples at 5 (wall) depths and 4 heights. A control value – a so-called zero sample – was also taken from an unaffected wall area. Further samples were taken in specific affected areas, such as where the roofing was defective. The moisture content of each sample was determined at the time of sampling as well as at 23°/50% RLF and 23°/80% RLF in order to clarify the influence of rising and hygroscopically caused increased moisture. The anion concentration of nitrates, sulphates and chlorides was determined from each sample. A cation determination was deemed necessary due to the clear pattern of the results.

The installation of the horizontal damp proof course was carried out as an advanced measure a whole year in advance of the desalination measures. In areas with extreme salt load, 4 cycles of desalination were required until no further indications of an increased residual salt load could be detected. After desalination, an internal insulation system was applied to a layer of earth levelling plaster. As the existing walls had exhibited dry rot infestation, a mineral internal insulation system was used.

08a Installation of the horizontal damp proofing and local foundation reinforcements

08b Sacrificial plaster with clearly recognisable localised incidence of hygroscopically increased moisture



09a and b The injection holes for the 1980s chemical horizontal damp proofing barrier are too far apart. In addition, the injection agent was chemically and physically incompatible with the stone it was injected into.

Qasr al Hosn, Abu Dhabi, United Arab Emirates

The Qasr al Hosn, formerly the seat of the ruling family of Abu Dhabi, is now open to the public as a museum and lies at the heart of Abu Dhabi between high-rise skyscrapers. ZRS Ingenieure GmbH was commissioned to undertake preliminary investigations of the moisture and salt contamination of the historic stone walls and worked together with the waterproofing expert assessor, Jens Koch, Potsdam. The engineers founded a local office – ZRS Ltd. Abu Dhabi – to oversee the overall conservation works with support from ZRS Architekten GmbH and ZRS Ingenieure GmbH in Berlin.

The historical stone walls were originally built using lime and coral bricks set in gypsum-lime mortar but over the course of many subsequent conversions, new building materials, such as reinforced concrete or cement plaster, were introduced that were not compatible with the original fabric. During a conversion phase in the 1980s, a chemical horizontal damp proof barrier was installed. Testing showed that moisture content levels above and below this barrier layer were roughly the same. Further investigations revealed that the closed pore structure of the original stone inhibited the spread of the injected chemical barrier. In addition, the distance between the injec-

10a Clearly visible indications of desalination during the third cycle of desalination measures

10b Qasr al Hosn, Abu Dhabi, UAE, after completion of desalination works

tion holes were, by current standards, too far apart. As a result, the chemical horizontal barrier had been largely ineffective since the very beginning.

After extensive preliminary investigation of the moisture and salt content in the soil and in the layers of the building fabric, we recommended the installation of a mechanical horizontal damp proofing barrier into the construction. The conservation authorities, however, did not give approval for such significant intervention into the historical substance. As a consequence, the repeated application of clay mortar as a salt reduction measure was undertaken as a means of at least extending the period of time until moisture and salt damage to the plaster surfaces may recur. Due to the lack of locally available suitable earth, a salt reduction mixture of bentonite powder and sand was mixed in a ratio of 1:5.

In January 2020, heavy rainfalls led to a strong increase in water ingress into the walls. Due to the lack of a horizontal waterproofing system, signs of renewed salt contamination have therefore already reappeared in the lower base area. Under normal environmental conditions, this had been predicted for a much later time horizon.

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