



TRANSPORT AND CRYSTALLISATION OF SALTS IN MASONRY AND PLASTERS

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Abstract

For the understanding of the salt crystallisation mechanism in restoration plasters, insight in the mechanism of moisture transport is essential, as well as in the influence of salts on that mechanism. More specifically the drying behaviour, i.e. the moisture / salt transport and distribution during drying, is important.

For a number of damage cases the salt and moisture distribution is analysed and, for some of the cases, the development of the damage over time is shown. The same is done for damage development in laboratory experiments. Recent experiments with NMR make it possible to understand better the moisture transport and the drying of porous materials. On the basis of the discussed examples, hypotheses are proposed on factors determining the salt damage mechanism.

Key Words

Salt damage, moisture, experiments, cases

1 Introduction

The most recurrent types of damage due to salt crystallisation processes, found both in practice and in laboratory are (Charola 2002):

- powdering or sanding
- scaling

Scaling mainly occurs when a thin surface layer, with properties slightly different from the rest of the material, exists. Once this surface layer is gone, the damage usually proceeds in the form of powdering.

Apart from that, a very clear and specific damage type may occur when surface treatments like water-repellents are applied:

- Spalling of a relatively thick layer, usually, but not always, the water-repellent zone.

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Several observations made in practice and in laboratory experiments will be discussed, aiming at a better definition of the moisture and salt solution transport and consequently of the conditions and mechanism of salt damage. The observations concern cases of sea salt decay (in situ) and of sodium chloride and sodium sulfate decay (in laboratory).

In order to assess the salt distribution, hygroscopicity of the salt loaded material has been measured. Hygroscopicity means absorption of moisture from the air; salts can absorb moisture from the air, when the Relative Humidity is above their equilibrium RH. For a given type of salt, a higher moisture absorption at a certain RH corresponds with a higher quantity of salt. Salt distributions given in this paper generally are based on the hygroscopic moisture absorption of (powder) samples at a RH of 96%. This RH was chosen in order to include the effect of both sodium chloride and sodium sulfate. Note that the equilibrium RH for NaCl is 75.6% and for $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ is 93% at 20°C. For the understanding of the salt crystallisation mechanism, the understanding of water (moisture) transport is essential, as it is the influence of salts on the water transport. For the decay occurring, the drying behaviour, i.e. the moisture transport and moisture and salt distribution during drying, is important.

2 Observations

2.1 The influence of salts on the rising damp in masonry

In a masonry wall, mortar and brick generally have a different pore size distribution, the mortar possessing finer capillaries than the brick. As a wider pore is not able to extract moisture from a finer pore, the interface between mortar and brick is a limiting factor for rising damp. This is illustrated in fig. 1a, (Van Hees 1980). Tammes and Vos (1980) suggested that the barrier could be overcome by the presence of salts. In order to assess the effect of salts, an experiment was set up and the behaviour of three walls, with their base in respectively tap water, water with 2.3% Na_2SO_4 and water with 5% Na_2SO_4 was compared. It was clear that indeed the brick mortar interface was the limiting factor. The obstacle constituted by the mortar/brick interface could however be overcome when a salt solution was used: in this case a higher level of rising damp was reached (see fig.1b,c). The higher salt concentration gave the higher level of rising damp. We suppose that the effect of the salts is either caused by the creep behaviour of salts (Pühringer 1983) or by a change of surface tension, due to the presence of the salts (Atkins, 1986).

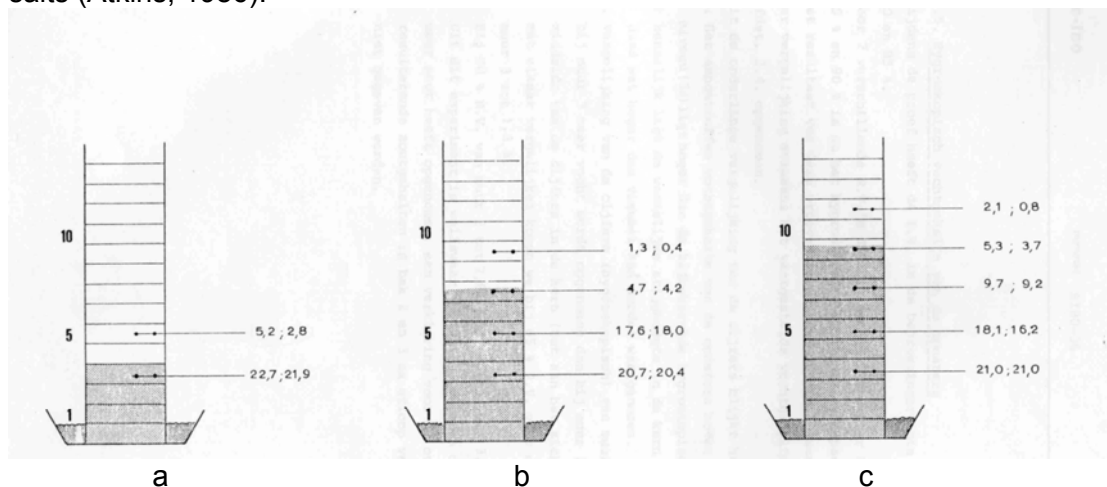


Fig. 1 The level of rising damp reached and the moisture distribution in 3 walls [3]. Without and with salts added to the water (wall a is the reference, without salts)

2.2 The influence of NaCl on the drying behaviour of brick

In a laboratory experiment the drying behaviour of brick was determined with the use of NMR (Pel 2002). The experiment was done first with water and is shown in fig. 2. A clear receding drying front is observed: the critical moisture content is reached.

When the same experiment was performed with a NaCl solution (1M solution) the result was completely different: no receding drying front was observed under equal environmental conditions, as can be seen in fig. 3. The occurrence of salt crystallisation on the surface was observed at the moment that the salt concentration near the surface reached 6M, the saturation concentration of NaCl (fig.4). It is interesting to observe that in the NMR measurements no supersaturation was reached. Pel et al (2002) and Pel (2002) suppose that NaCl does not supersaturate and therefore postulate that any damage occurring with NaCl can not be attributed to stress developed by crystallization at supersaturation of the NaCl solution. Since, according to Correns' theory (Correns1948), the crystallization pressure is related to the degree of supersaturation, NaCl would not be able to develop high pressures. Further, Rodrigues-Navarro and Doehne (1999) state that cubic halite crystals result from crystallization at low supersaturation and these are supposed to be less harmful than the prismatic crystals growing at high supersaturation ratio. This may explain why in many laboratory experiments (see also the next example) it is much more difficult to have damage to building materials due to NaCl than due to Na_2SO_4 .

The serious damage, due to sea salts, observed in reality may then be explained either by the presence of other salts together with NaCl (changing the supersaturation ratio of the solution) or by damage mechanisms different from crystallization pressure.

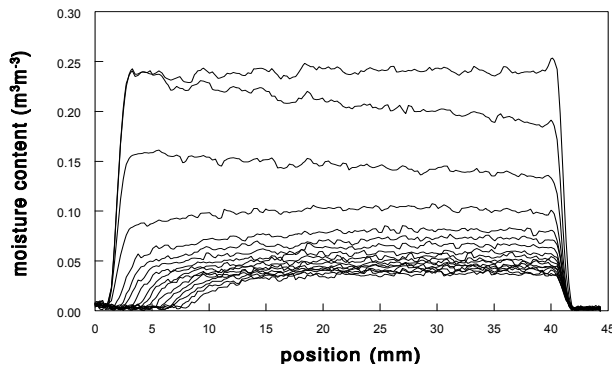


Fig.2 Drying behaviour of Dutch brick with water. Moisture distribution during drying. Time between different profiles 1 h. (NMR measurement, Pel 2002)

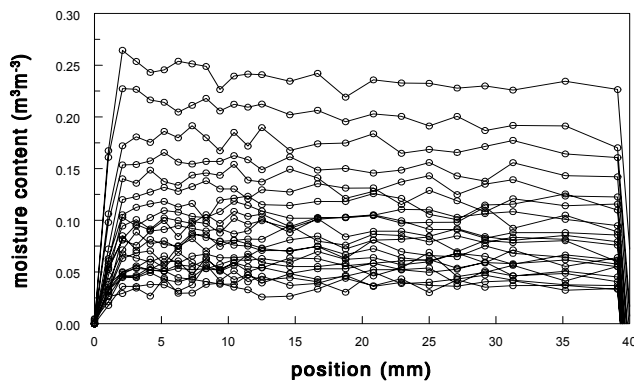


Fig.3 Drying behaviour of Dutch brick with NaCl solution. Moisture distribution during drying. Time between different profiles 3 h. (Pel 2002)

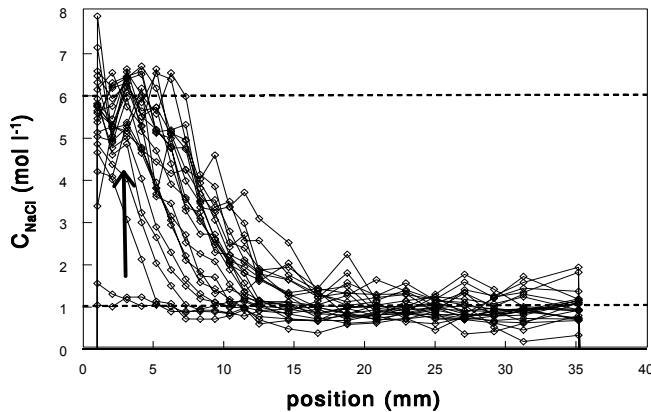


Fig. 4 NaCl-concentration distribution for Dutch brick during drying. Time between different profiles 3 h. Sample initially saturated with 1M solution (Pel 2002)

2.3 Plasters based on salt transporting principle, a solution against salt damage?

Two cases are described in which a salt transporting plaster was applied on a substrate containing sea salts.

The first case is a church in the province of Zeeland in the Netherlands. In the 1950's large part of the province was flooded by the sea. Walls of buildings absorbed a considerable quantity of sea salts. In the church of Brouwershaven the plaster was heavily damaged and replaced first by a bituminous layer with a cement-sand plaster on top. Although during a long period no major damages were observed, this layer was in the end suffering serious damage. This plaster was finally replaced in the 1990's (ca. 25 - 30 years after the application) by a restoration plaster based on the salt transporting principle.

After ca. 5-8 years the new restoration plaster, although generally recommended in the Netherlands for substrates with a high salt load, started to suffer damage.

We suppose that, due to rising damp and to the prevention of evaporation through the surface of the first plaster, with the bituminous layer, salts have been deposited at a much higher level than reached by the flood.

Fig. 5a gives an overview of an internal wall in the church in respectively 2000 and 2002 (18 months later). Comparison of both overview photographs makes clear that the damage is increasing.

Fig. 5b gives the moisture distribution of the wall concerned, at location B. It can be seen that there is rising damp in the wall, currently up to a level of ca. 2 m. From the hygroscopic moisture distribution, the presence of a concentration of the salts around a height of ca. 3 m (and as can be seen from the actual damage, even reaching a higher level) can be assessed. The salt efflorescence collected at this height was analysed and was found to be mainly NaCl.

The most severe damage can be described as crumbling and falling apart of the plaster. In general the damage development starts with peeling of the paint, probably together with powdering of the plaster directly underneath. The damage further develops first following the pattern of hair cracks (craquelé) present in the plaster. In the next stage powdering and sanding of the plaster surface occurs, starting near hair cracks, until finally crumbling takes place, leading to complete segments, surrounded by hair cracks, falling apart.



Fig. 5a Evolution of the damage at location B

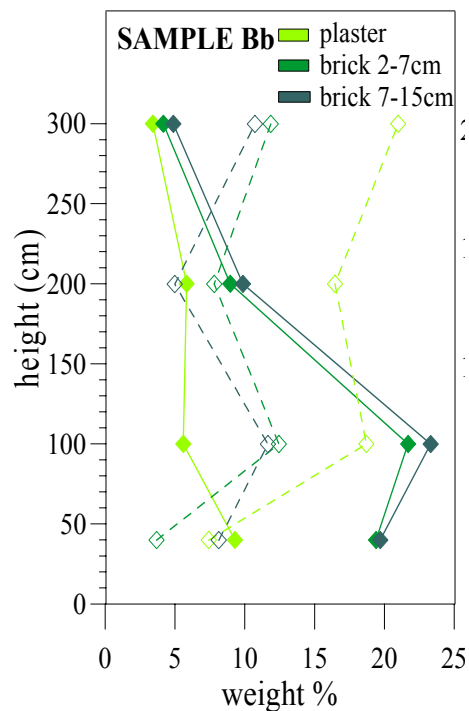


Fig. 5b Moisture and hygroscopic moisture distribution at location B

Since the most affected parts are above the upper limits of the height nowadays reached by rising damp, damage can not be due to crystallisation from the solution supplied by rising damp, but has to be related to changes in the indoor environment (mainly RH changes). The T and RH changes have been monitored. It was found that regularly changes around the RH of 75%, the equilibrium RH for NaCl, occur, leading to a great number of deliquescence – crystallisation cycles. We suppose on the basis of preliminary results of still running experiments, that deliquescence – crystallisation cycles of the salts present in the pore system near the plaster surface, rather than crystallisation pressure, cause an irreversible (hygric) expansion that leads consequently to powdering / sanding of the surface.

A similar type of damage was found at Curaçao (NA) where the same type of plaster was applied on a building affected by salt damage.

During the restoration a quite heavy salt load was assessed. Historic buildings at Curaçao quite often have been built with mortars, making use of sea water and with salt containing building stone (Van Hees, 1991). Because of the high salt load and the presence of rising damp, this specific restoration plaster was advised and applied at the external wall surfaces. The substrate consisted of a local, quite coarse porous, lime stone. A service life of between 5 and 10 years without damage was expected.

After 1 to 2 years from the restoration, damage occurred. The damage development was quite similar to the one described for Brouwershaven: detachment of the paint and sanding of the plaster surface. Once the paint had disappeared, a clear craquelé pattern was visible in the surface; starting from the hair cracks damage proceeds to the complete falling apart of sections surrounded by the hair cracks. Fig. 6 gives some details of the damage development.

As in this case an external wall surface is concerned, the environmental conditions can be considered more severe with respect to salt crystallization damage: apart from RH cycles also a higher temperature and temperature cycles (air temperature varies between 23 and 37 °C) occur. And further the plaster is exposed to rain. Damage development is therefore quicker and more severe. The same plaster, used on other buildings at Curaçao, showed a much longer service life, with as clearest difference the porosity structure of the substrate, that is usually much finer.



Fig. 6 Curaçao (NA) - nb colour differences due to the use of different camera types

Critical conditions in these cases are obviously:

- heavy salt load in the substrate (NaCl)
- coarse porous substrate (brick and coarse porous limestone)
- RH fluctuations through the RH of equilibrium of NaCl (75.6%)
- Fast drying due to high temperature (in the case of Curaçao)

These conditions, proved to be critical in reality, were reproduced in laboratory tests as described in the following chapter.

2.4 Plasters based on salt accumulating principle: laboratory experiments

A salt accumulating plaster generally consists of two layers: the base coat, that should allow salts to penetrate and eventually crystallise, and the topcoat, that has water repellent properties and should not be invaded by the salts.

In the laboratory experiment presented here, a salt accumulating plaster constituted of two layers without paint on the surface was applied on a brick substrate.

In the experiments the effect of different environmental circumstances and their capacity to accelerate salt transport and eventual damage were investigated. Two different regimes were used (continuous absorption of NaCl solution and initial contamination with NaCl solution followed by repeated wetting with water) together with six different environmental conditions. The test was performed both on brick/plaster combinations. A summary of the different regimes and environmental conditions is given in table 1.

Fig.7 shows that all circumstances result in the same tendency: salts concentrating in the base coat, but also penetrating a bit in the top coat. The T and RH cycles show the highest quantity of salts in the accumulating base coat. For the wetting from behind a repeated wetting appears to provoke a higher salt content in the base coat than continuous absorption of solution from the backside. This may be due to a redistribution by diffusion of the ions back in the wet substrate in the latter case.

Remarkable is that in this type of restoration plaster salts (i.e. NaCl) are present, although in a low quantity, also in the water repellent part.

Table 1 Regimes and conditions used in the laboratory test on salt accumulating plasters

brick/ plaster specimens	20°C 50% RH	50°C 50% RH	50°C 35% RH	20-50°C 50%	20°C 50-96%RH	T / RH cycles (20-50°C; 55- 15%RH)
dry-wet cycles	const.	const.	const.	1week cycle	1week cycle	1 day cycle
contin. absorption	const.	const.	const.	1week cycle	1week cycle	1 day cycle

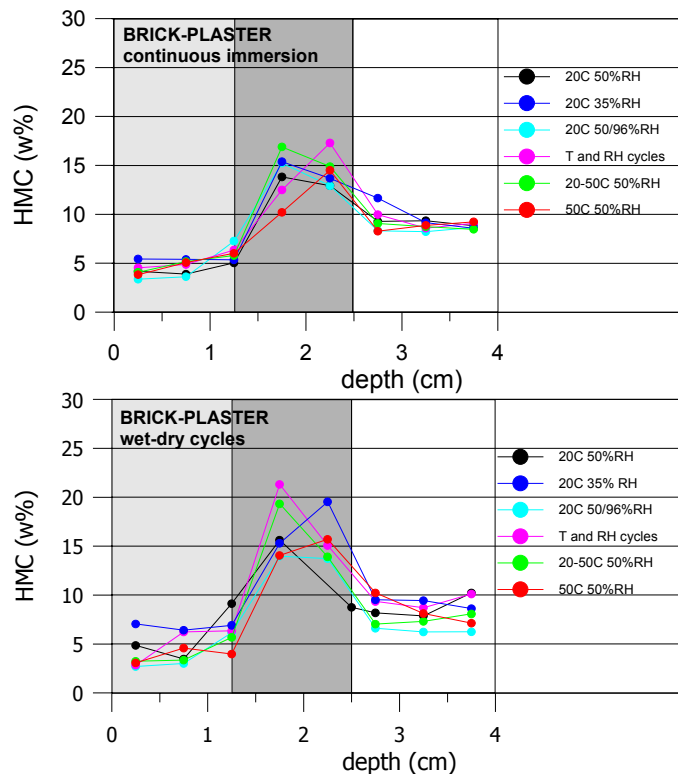


Fig.7 Salt distribution in accumulating plasters

3 Discussion and conclusions

Several observations were made in practice and in laboratory experiments that make it possible to better define conditions that favour the occurrence of salt damage. The understanding of the damage mechanism, especially of NaCl, is growing. However, further research on the damage mechanism is still necessary in order to develop plasters both of the salt accumulating and salt transporting type with a better salt durability.

Central questions appear to be:

- What is the exact damage mechanism causing salt damage
- Can the occurrence of damage and or the mechanism be influenced by mortar / plaster design
- is the influence of environmental conditions (and kinetics) more important than mortar properties

Factors influencing the damage are deriving from the described situations:

- Type of salt: NaCl is less aggressive than Na₂SO₄. This seems to be related, according to the experiment by Pel c.s., to the fact that no super-saturation appears to be reached by NaCl when crystallization occurs. Crystallization pressure is in fact proportional, according to Correns' theory, to the super-saturation level. The importance of supersaturation in relation to the seriousness of the damage has to be further verified by comparing the supersaturation level for Na₂SO₄ at crystallisation in a similar experiment as was carried out for NaCl and by studying the possible effect of the presence of other salts on the level of supersaturation that can be reached by NaCl. This might partly explain the difference between considerable damage in reality, where most of the time a mix of salts is present and more extreme environmental conditions may occur, and the relatively limited decay surveyed in laboratory tests performed with NaCl.
- Type of substrate: a coarse porous substrate constitutes a higher moisture supply to the plaster, that usually is rather fine porous. It enhances the suction of water (or solution) by the plaster; clear indications from practice, as well as from experiments in the running EU project COMPASS⁷, exist. A study of the properties of the plaster in relation to that of the substrate (including a theoretical model of salt solution transport in brick/plaster system) will help to reach more appropriate solutions in case of restoration of salt contaminated substrates.
- Presence of wet-dry cycles: if the salt loaded masonry is subjected to repeated wetting and drying, the damage is accelerated. This is visible in reality, where the maximum damage is present at the level of the capillary rise fringe where most wet-dry cycles occur, and in laboratory experiments, where the most serious damage has been observed when repeated wetting and drying are produced
- Temperature: high temperature and/or temperature cycles appear to accelerate the damage; this is demonstrated in reality by the very serious and fast damage surveyed in salt transporting plasters applied in Curaçao; a similar indication was found in laboratory where a lime plaster shows damage in case high temperature (cycles) are used. Whether this is related to the fast drying or to the occurrence of temperature cycles is still not clear. The importance of mechanisms, like the effect of salts on thermal expansion and consequent shear stress, has to be considered and verified. Studying the thermal expansion in salt contaminated plasters will give an answer and will help in finding new accelerated laboratory NaCl crystallization tests.
- Presence of RH cycles: just RH changes through the RH of equilibrium of the salt are able to generate damage. This has been observed in the interior of the church showing damage in location where no rising damp, i.e. no wetting with liquid water, was present. This factor is more important for hygroscopic salts, like NaCl, having an equilibrium RH common in indoor and outdoor environment. If the damage is only related to dissolution of the salts at high RH followed by crystallization at low RH leading to crystallization pressure, or if mainly (irreversible) dimensional changes in the salt laden material due to moisture uptake and drying are involved is not proved yet. New experiments such as crystallization test using RH cycles are either running or will be set up to verify the phenomenon and quantify its importance.

⁷ Compatibility of Plasters and Renders with Salt loaded Substrates in Historic Buildings, EU contract nr. EVK4-CT-2001-0047 - DG XII, web-site: www.compass-salt.org.

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