

Salt Damage and RH Changes: The Case of the Waag Building in Amsterdam

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Abstract

Changes in the air RH can cause damage to building materials contaminated with hygroscopic salts, even in the absence of any other moisture source. This phenomenon has been observed in the case of the *Waag* building in Amsterdam, affected by severe salt decay. The investigation, carried out by means of different techniques (e.g. ESEM-EDX, IC and XRD), has revealed the presence in the masonry of a large amount of hygroscopic salts (mainly sodium chloride and nitrates) and the absence of any moisture sources other than the RH of the air. Besides, an adsorption experiment performed on samples from the building has pointed out the hygroscopic moisture uptake of the salt mix even at low RH. These results, in combination with a monitoring of the interior climate for a period of about 1 year, have allowed to conclude that the damage observed is due to the frequent RH changes through the equilibrium where dissolution/crystallization of the salt mix takes place. On the basis of these findings an advice for the conservation of the building was given.

Keywords: Hygroscopic salts, moisture content, salt damage.

Salzschäden und Veränderungen der relativen Luftfeuchtigkeit: das Gebäude de Waag in Amsterdam, ein Fallbeispiel

Zusammenfassung

Wenn Werkstoffe des Bauwesens mit hygroskopischen Salzen belastet sind, können bereits Änderungen der relativen Luftfeuchtigkeit Schäden verursachen; hierzu braucht es keinerlei andere Feuchtigkeitsquellen. Diese Erscheinung wurde in Amsterdam am Gebäude „de Waag“, an dem starke Salzschäden zu beobachten sind, untersucht. Mit Hilfe von Analysen mit unterschiedlichen Methoden, wie etwa ESEM-EDX, IC und XRD, konnte festgestellt werden, dass sich im Mauerwerk eine große Menge hygroskopischer Salze befindet, in der Hauptsache Natriumchlorid und Nitrate, und dass als Feuchtigkeitsquelle ausschließlich die Feuchtigkeit der umgebenden Luft in Frage kommt. Außerdem ergaben Versuche zur Adsorption, die an Proben aus eben diesem Gebäude durchgeführt wurden, dass durch die Salzmischung bereits bei niedrigen relativen Feuchtigkeiten hygroskopisch Wasser aufgenommen wird. Diese Ergebnisse, in Verbindung mit der Beobachtung des Innenklimas über einen Zeitraum von etwa einem Jahr, erlauben es uns zu folgern, dass der zu beobachtende Schaden durch häufige Wechsel der relativen Luftfeuchtigkeit hervorgerufen wird. Im Gleichgewicht mit der umgebenden relativen Luftfeuchtigkeit finden abwechselnd Lösen und Kristallisieren der Salze statt. Auf der Basis dieser Ergebnisse, wurde eine Empfehlung für die Konservierung dieses Gebäudes erstellt.

Stichwörter: Hygroskopische Salze, Feuchtigkeitsgehalt, Salzschädigung.

1 Introduction

Salt crystallization can cause severe damage to porous building materials. Salt, crystallizing in the pores, creates pressures which weaken and finally damage the material [1, 2]. Repeated dissolution/crystallization cycles of the salts increases the risk of damage. Most of the salts commonly found in masonry are hygroscopic, i.e. they adsorb moisture from the air if the RH of the air is higher than their RH of equilibrium (RH_{equ}). If the adsorbed moisture is enough, the salts (partially) dissolve, and then re-crystallize once the RH of the air decreases again below the RH_{equ} . For individual salts the RH_{equ} is well known [3], whereas for salt mixtures it needs to be measured or calculated [4]. Depending on the climate conditions and on the kinetics of the specific salts (dissolution and crystallization can occur rapidly or very slowly [5, 6]), cycles of crystallization/dissolution may take place leading to severe damage [7, 8].

In the following sections the case of the Waag building is presented and discussed. The investigation consisted of sampling, monitoring of the interior climate and laboratory analyses on the collected materials for the determination of the moisture source and the salt types and distribution. On the basis of the results of this research a diagnosis of the damage process was made and an approach for the conservation of the building was proposed.

2 The Waag Building: History and State of Conservation

The Waag building in Amsterdam (Fig. 1) is a remnant of the former city walls (1481-1492); originally it was one of the city gates (St. Antoniespoort). When in the late 16th century the city expanded, the wall was torn down and the gate lost its function. The defensive canal and palisade around the gate was turned into a market square. The upper floors housed four guilds for some time, namely those of the smiths, painters, masons and surgeons. Each guild had its own entrance tower.

The object of this research is the tower belonging to the masons' guild. In this tower master proofs of the masons' guild are located whose curved shapes (Fig. 2), often in perspective, are testimonies of the high mathematical and technical skills reached by the master masons. After the guilds were dissolved around 1795, the building served numerous purposes, later housing a fire brigade and two museums before it was handed over in 1990 to the Waag Society, an ICT research foundation working in the social and cultural domain.



Figure 1: The Waag building in Amsterdam.



Figure 2: Detail of the master proofs in the mason's tower

Severe salt crystallization damage affects the master proofs in the masons' tower. The bricks show powdering, and in some cases, scaling of the outer surface (Fig. 3). The very thin mortar joints show powdering and, at some locations, they are completely gone. There is no clear pattern in the decay: damage is present both in the lower and in the upper part of the tower. At some locations the damage seems to start at the joint and to develop then into the brick, whereas at some other locations the mortar is still sound while the brick is completely powdered. The natural stone, which was used at the door entrance on the first and 2nd floor, shows damage too.



Figure 3: Powdering of the brick in one of the master proofs on the 1st floor of the tower

3 Sampling and Investigation Methods

3.1 Sampling

Three sampling campaigns were performed: in November 2004, in February 2006 and in July 2006 during which the following samples were taken:

- 21 (in the 1st campaign), 44 (in the 2nd campaign) and 21 (in the 3rd campaign) powder samples were collected for the investigation of moisture and salt. Brick, stone and mortar samples were collected at several locations and at different depth at the ground floor, the 1st and 2nd floor of the tower (see Table 1).
- 2 efflorescence samples were scratched from the surface of two bricks for the determination of the salt type
- scales from the surface of the brick and of the mortar joint were collected to be observed in the ESEM-EDX
- pieces of brick and mortar were taken for the assessment of the pore size distribution

3.2 Laboratory Analyses

The actual and hygroscopic moisture content at 80 % (HMC₈₀) and at 96 % RH (HMC₉₆) of the powder samples was determined gravimetrically [9]. The HMC gives an indication of the amount of hygroscopic salts present. If the HMC measurements are performed at different RH, an indication of the type of salts can be obtained as well [10].

Ion chromatography (IC) was performed by a Dionex ICS 90 chromatographer on a selection of 9

of the powder samples, in order to determine the type and amount of ions.

XRD analyses were performed (by means of a Philips PW3020 X-ray diffractometer) on 2 samples of efflorescences scratched from the surface of 2 bricks.

The ESEM observations on brick and mortar scales have been performed by means of a Tungsten XL 30 Environmental Scanning Electron Microscope (ESEM) of FEI, equipped with an Energy Dispersive X-ray (EDX) system of EDAX. ESEM investigations have been carried out mainly by the use of a Back Scattered Electron (BSE) detector. EDX analyses and mapping of Cl, Na, Ca, Si, Mg and S ions have been performed to identify the salts and the material components.

The pore size distribution of the brick and of the mortar has been measured by Mercury Intrusion Porosimeter (Autopore IV/9500 by Micromeritics) on samples previously desalinated by repeated immersion in demineralized water.

3.3 Environmental monitoring

The indoor climate in the tower has been monitored for a period of about one year, in order to study the effect of the environmental conditions on the salt damage. Data on the temperature (T) and Relative Humidity (RH) of the air have been collected by means of ESCORT sensors placed at different locations: in the tower at the ground floor, the 1st and 2nd floor, and in the “*gildekamer*” on the 1st floor.

3.4 Adsorption experiment

An adsorption experiment has been performed in laboratory to determine the hygroscopic moisture uptake of the salt mixture present in the wall. The experiment consisted in storing the sample on a balance in a climatic cabinet and recording its weight variation when increasing the RH. In this experiment the weight of the sample is recorded continuously: when the sample has reached a constant weight the RH is increased. The temperature in the climatic cabinet is kept constant at 23 °C, while the RH is increased step by step from 28 % to 96 %. The experiment has been performed on 2 powder samples (1b and 36b) to get an indication of the RH at which hygroscopic adsorption starts in this masonry contaminated with a salt mixture. In fact, while the RH of equilibrium of a single salt is well known, the RH of salt mixtures is difficult to be calculated.

Table 1: Location, material, MC and HMC of the samples

Sample code	MC	HMCat 96%	HMCat 80%	Sample code	MC	HMC at 96%	HMC at 80%	Sample code	MC	HMC at 96%	HMC at 80%
36aB _{0,0-1}	3.0	30.4		36bM _{0,1-5}	3.7	45.7	27.2	35bS _{2,0-1}	0.2	30.0	18.6
37aB _{0,1-5}	3.4	32.4		37bM _{0,5-10}	3.2	35.5	22.0	34bS _{2,1-5}	0.2	10.5	5.8
38aB _{0,10-15}	4.1	46.2		41bB _{0,0-1}	1.1	8.0	4.6	1NbB _{2,10-15}			7.6
39aB _{0,0-1}	2.8	36.9		42bB _{0,1-5}	0.5	7.9	4.2	2NbB _{2,5-10}			5.5
40aB _{0,1-5}	2.7	34.4		43bB _{0,5-10}	1.9	9.3	3.7	3NbB _{2,0-5}			5.7
41aB _{0,10-15}	3.8	35.2		44bB _{0,0-1}	3.4	20.7	6.9	4NbM _{2,10-15}			24.1
42aB _{0,0-1}	1.5	23.1		45bB _{0,0-1}	2.6	10.5	2.6	5NbM _{2,5-10}			28.9
43aB _{0,1-5}	2	25.5		13bB _{1,0-1}	0.7	4.1	1.7	6NbM _{2,0-5}			18.9
44aB _{0,0-1}	0.7	20.6		12bB _{1,1-5}	0.4	2.4	1.0	39cB _{1,0-1}	0.0	23.3	14.4
45aB _{0,1-5}	1.6	34.6		11bB _{1,5-10}	0.9	2.7	1.2	40cB _{1,1-5}	0.0	15.6	10.5
46aB _{0,10-15}	1	42.1		10bM _{1,10-15}	1.1	4.9	2.2	41cB _{1,5-10}	0.0	11.6	7.6
47aB _{0,0-1}	2.9	32.9		16bB _{1,0-1}	1.2	4.3	2.1	42cB _{1,10-15}	0.0	33.3	16.7
48aB _{0,1-5}	3.4	37.6		15bB _{1,1-5}	0.2	3.0	1.2	43cB _{1,0-1}	0.0	3.9	3.9
49aB _{0,0-1}	2.1	32.4		14bB _{1,5-10}	0.9	1.8	0.0	44cB _{1,1-5}	0.0	3.6	2.7
50aB _{0,1-5}	2.2	25.7		20bB _{1,0-1}	1.8	10.6	4.7	45cB _{1,5-10}	0.0	3.6	2.7
51aM _{0,0-1}	5.8	33.3		19bB _{1,1-5}	0.6	9.8	5.3	46cBM _{1,10-15}	0.0	9.5	7.1
52aM _{1,0-2}	1.5	93.1		18bB _{1,5-10}	1.7	9.8	4.0	47cS _{1,0-1}	0.0	10.4	6.7
53aM _{1,2-5}	0	54.0		17bB _{1,10-15}	1.9	10.4	4.7	48cS _{1,1-5}	0.0	7.6	4.7
54aB _{1,0-1}	0	12.6		24bB _{1,0-1}	1.0	5.3	1.9	49cS _{1,5-10}	0.0	5.0	3.0
55aB _{1,1-5}	0	10.3		23bB _{1,1-5}	0.7	5.1	2.1	50cM _{2,0-1}	0.1	22.9	15.0
6bB _{0,2-5}	4.2	22.2	14.0	22bB _{1,5-10}	0.8	5.0	1.5	51cB _{2,0-1}	0.0	22.1	15.0
7bM _{0,2-5}	4.1	33.4	20.5	21bB _{1,10-15}	0.6	5.2	2.1	52cB _{2,0-1}	0.0	27.9	20.2
8bM _{0,0-1}	14.6	36.6	19.5	29bB _{2,0-1}	1.2	22.5	11.9	53cB _{2,1-5}	0.0	19.9	17.5
9bBM _{0,0-1}	4.3	32.2	17.8	28bB _{2,1-5}	1.0	13.5	6.0	54cB _{2,5-10}	0.0	19.3	14.0
5bB _{0,0-1}	0.0	10.4	4.5	27bB _{2,5-10}	0.2	11.3	5.9	55cM _{2,0-2}	0.0	9.0	7.0
4bB _{0,1-5}	1.6	16.9	9.1	26bB _{2,10-15}	0.0	8.2	3.3	56cM _{2,0-2}	0.0	7.5	5.5
3bM _{0,5-10}	2.0	27.4	13.7	33bB _{2,0-1}	0.7	13.6	8.1	57cB _{2,0-1}	0.0	2.2	0.7
38bB _{0,0-1}	0.8	7.1	3.3	32bB _{2,1-5}	0.2	8.4	4.3	58cB _{2,1-5}	0.0	1.2	0.6
39bB _{0,1-5}	0.9	7.3	4.1	31bB _{2,5-10}	0.2	8.2	3.9	59cB _{2,5-10}	0.0	2.1	1.1
40bB _{0,5-10}	2.1	13.5	6.2	30bB _{2,10-15}	0.2	4.8	2.0				
1bB _{0,0-1}	3.0	37.9	21.2	25bM _{2,0-2}	2.0	13.1	8.4				

$n \times Y_{z,j-k}$ n = sample number

x = sampling campaign (a=winter 2004; b = winter 2006; c = summer 2006)

Y = material (B = brick; M = mortar; S = natural stone)

z = floor (0 = ground floor; 1 = 1st floor; 2 = 2nd floor)

$j-k$ = depth of sampling in cm

4 Results

4.1 Actual (MC) and Hygroscopic Moisture Content (HMC)

Regarding the moisture content of the samples (Table 1) the following conclusions can be drawn:

- All the samples, with the exception of sample 8b collected above the entrance door, show a low MC; the MC is always lower than the HMC.
- The moisture distribution as found in the pillar at the ground floor (samples 36-46a) excludes rising damp as a relevant source of moisture
- No significant differences in MC have been observed between samples from external and internal walls. This excludes rain penetration as a possible moisture sources. Only in the case of sample 8b, rain penetration may be present.
- The MC is generally higher in the samples collected in the winter, when the RH in the not-heated spaces showed to be higher, than in the ones collected in the summer, when the RH was lower. This, together with the fact that the samples with a high MC generally also have a high HMC, makes probable that the MC is due to hygroscopicity.

Regarding the HMC the following conclusions can be drawn:

- The HMC₉₆ is generally high; this is a clear indication for the presence of hygroscopic salts. Also the HMC₈₀ is high, indicating that the salts are very hygroscopic.
- The HMC may extremely vary from one sampling location to another.

4.2 Ion Chromatography

The results of the ion chromatography (IC) are reported in Fig. 4. The ion content has been

expressed as mmole/g in order to point out ratios between anions and cations; on the basis of this ratio, hypotheses can be formulated on the presence of certain salts. On the basis of the obtained results it can be concluded that:

- NaCl is the main salt present. The Na/Cl molar ratio of about 1 indicates the presence of NaCl. NaCl is present in all the samples analyzed by IC. In some of the samples very high Cl (up to 1.2 wt %) and Na (0.9 wt %) contents have been measured.
- Apart from chlorides, nitrates are present too. Chlorides and nitrates are very hygroscopic salts, which start adsorbing moisture at a quite low RH (RH_{equ} at 20 °C: NaCl = 75.5 %; NaNO₃ = 75.4 %). This explains the high HMC₈₀ values.
- Sulfates are present in large quantities in samples 36b, 10b, 44b and 45b. It can be reasonably supposed that in samples 20b, 44b and 45b they are mainly present combined into gypsum (CaSO₄·2H₂O). Gypsum is not very hygroscopic: this explains the quite low HMC measured in these samples in spite of their high sulfate content. The hypothesis of the presence of gypsum is also supported by the XRD analyses performed on the efflorescences (§ 4.3).
- No clear differences have been detected in salt type and content between mortar and brick samples.

4.3 XRD Analyses

The results of XRD analyses (Table 2) show that silica (SiO₂) and calcite (CaCO₃), being these the main components of the brick and the mortar, are present in large quantities. Also gypsum (CaSO₄·2H₂O) is present in significant amount; low amounts of NaCl have been detected in one of the samples. These results are related to the detection limits of the XRD technique which can only identify compounds present in a percentage higher than 3-5 %.

Table 2: Semi-quantitative results obtained by XRD analyses

Compound	Chemical formula	Semi-quant. [%]	
		Sample 1	Sample 2
Quartz	SiO ₂	74	22
Gypsum	CaSO ₄ ·2H ₂ O	16	48
Calcite, syn	CaCO ₃	9	28
Halite, syn	NaCl	-	2

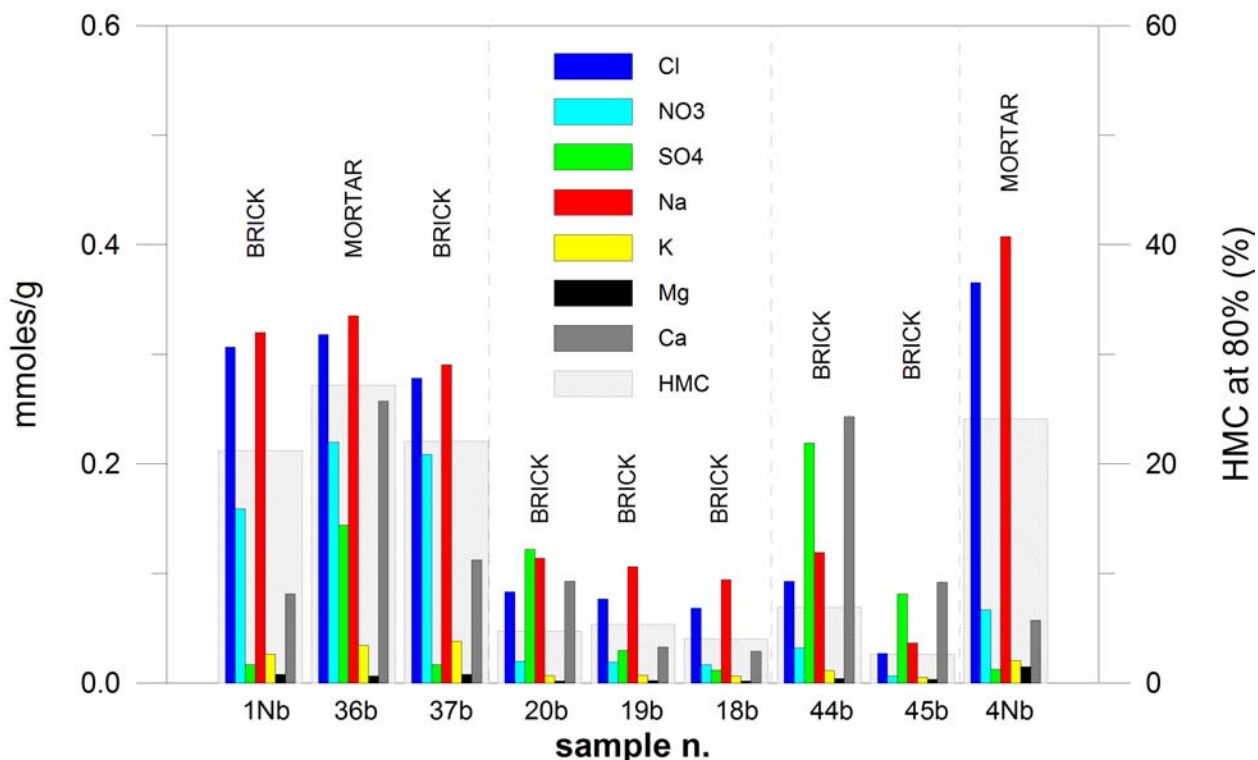


Figure 4: Results of IC performed on powder samples

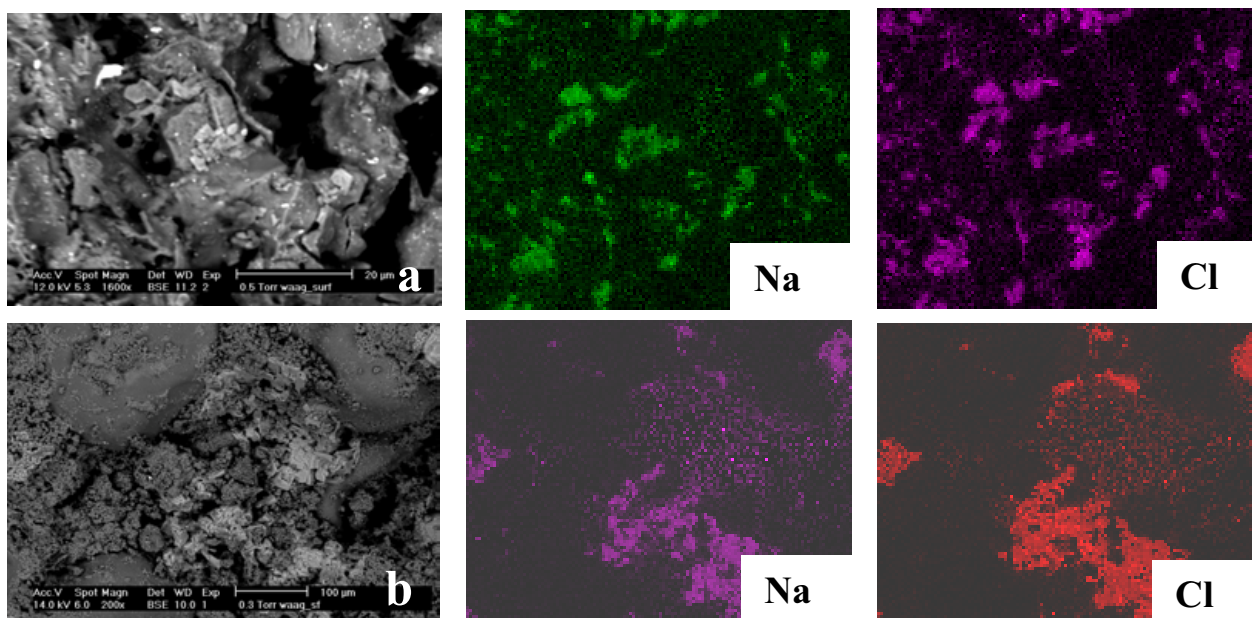


Figure 5: Na and Cl mapping performed by EDX on brick (a) and mortar (b) samples

4.4 ESEM Study

The ESEM observations performed on a brick flake show the presence of salt crystals which have been identified, by EDX mapping, to be NaCl (Fig. 5a). Similar results have been obtained on the mortar sample (Fig. 5b).

4.5 Pore Size Distribution

The pore size distribution and the total porosity of the brick and the mortar are reported in Fig. 6. The brick has an open porosity of about 35 vol % with pores in the range between 2 and 5 μm : thus a moderately fine porous brick with a quite high

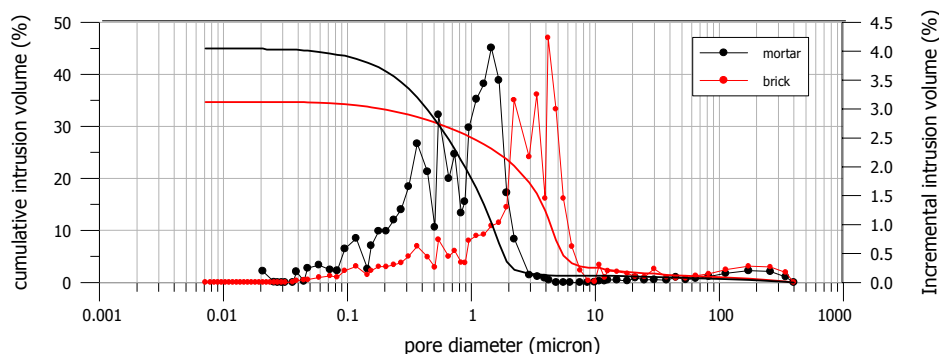


Figure 6: Open porosity and pore size distribution of the brick and the mortar as determined by MIP

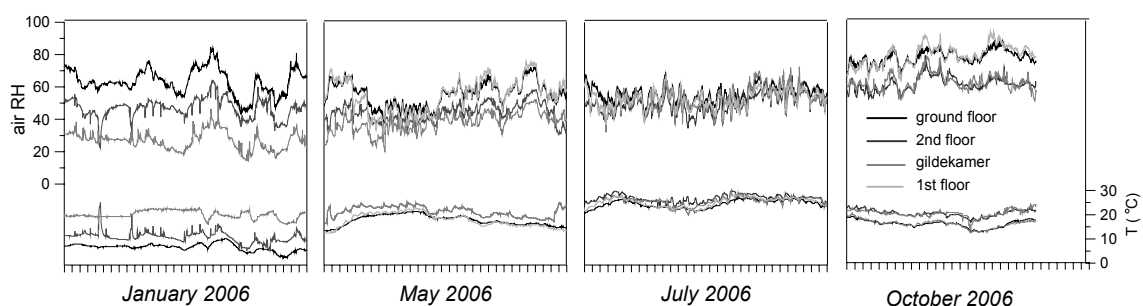


Figure 7: Temperature and RH at different locations in the building

porosity. The mortar has a high total open porosity (about 45 %) constituted by pores smaller than 1 μm . The absence of larger pores is due to the fact that no aggregate is present in this lime mortar. Knowing that moisture transport occurs from larger to smaller pores because of difference in capillary pressure, it is possible to conclude that in this case salt transport takes place preferentially from the brick to the mortar joint.

4.6 Environmental Monitoring

From the elaboration of the environmental data (Fig. 7) it emerges that:

- In the staircase, at the ground level and at the 1st floor, the RH reaches very high values (up to 90 %) in the winter. RH changes between 60 and 90 % RH occur. In the summer months the RH varies between 40 and 70 %.
- In the *gildekamer* and on the 2nd floor the RH can recede in the winter below 30 % due to the use of a heating system. While the *gildekamer* is continuously heated, the small room on the second floor is intermittently heated: this causes there fast RH variations between 20 and 60 % RH.
- In the winter large differences in RH exist between the not heated and the heated spaces.

In the summer these differences disappear and the RH varies between 40 and 70 % for all locations.

4.7 Adsorption Experiments

The results of the adsorption experiment are reported in Fig. 8. The adsorption curve of sample 36 shows a clear increase in the hygroscopic moisture uptake between 70 and 76 % RH, which corresponds to the RH_{equ} of NaCl, the salt present in large quantity in this sample (see IC results). Some moisture adsorption is present also at lower RH. This can be due to the presence of other salts (the ion chromatography indicated the presence of nitrates). The adsorption curve for sample 1 does not show any clear step; it can be observed that the slope of the adsorption curve increases at 50 % and then again at 70 % RH. Also in this case, the presence of a salt mix is responsible for this behaviour.

It can therefore be concluded that the hygroscopic moisture uptake already starts at 50 % RH and becomes more relevant for RH higher than 65 %. This confirms that frequent RH changes through these values enhance the development of the damage by causing dissolution/crystallization cycles of the salt present in the masonry.

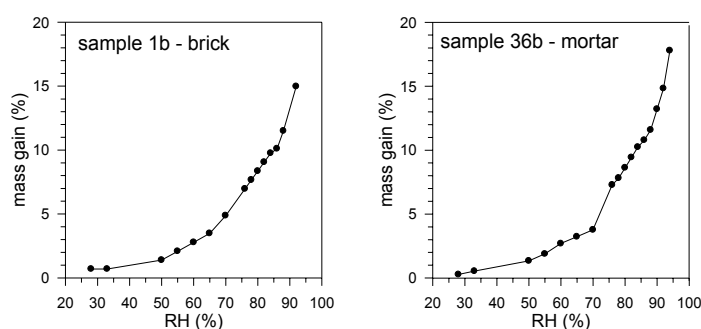


Figure 8: Adsorption curves of sample 1b (left) and 36b (right)

5 Discussion and Conclusions

From the research performed it can be concluded that the damage in the Waag building is due to the presence of hygroscopic salts in the masonry in combination with variations of the air RH.

The IC, EDX and XRD analyses show that chlorides and nitrates are present in the masonry: these salts are very hygroscopic, i.e. adsorb moisture from the air at a relatively low RH. The adsorption experiment has determined that the salt contaminated material starts adsorbing moisture from the air already at 50 % RH and, in a larger amount, at 65-70 % RH. Monitoring of the indoor climate in the Waag building revealed that the RH often varies across these RH values. This means that the salts present in the wall will adsorb moisture from the air and dissolve when the RH increases above these values and then re-crystallize when the RH decreases. These cycles are more frequent on the ground and 1st floor than in the *gildekamer* and on the 2nd floor: this explains why the decay is more severe on the walls of the staircase than on the second floor or in the *gildekamer*, even if no clear differences in salt content have been measured between the different locations.

The origin of the salts present in the wall is difficult to define. NaCl can not be present originally in the brick, since it would have been eliminated during the firing process. The hypothesis that NaCl comes from the mortar seems not probable because of the quantity of material of the very thin joints being unable to provide such a high NaCl amount as the one found in the masonry and because of the salt distribution which does not show any clear difference in salt content between mortar and brick. Besides, the pore size distribution of the brick/mortar combination does not favour the salt solution transport from the mortar to the brick.

On the basis of the results obtained, an advice for the conservation of the masonry master proofs can be formulated. In order to limit the damage development two options exist: eliminate or reduce the salt amount by desalinating the wall and/or control the RH of the air in order to limit dissolution/crystallization cycles.

In this case the moisture adsorption starts already at low RH (50 %), therefore controlling the climate in order to keep the RH always lower than 50 % does not seem the best option. This would require a system of air conditioning (the RH is high also in the summer) implying measures (sealing of doors, window etc.) which are considered very invasive from the point of view of conservation of the building. The hypothesis of maintaining the RH always higher than the RH of crystallization of the salt mix is not considered realistic, because it would be uncomfortable for the people working in the building and have a high risk of indoor mould growth and/or surface condensation. Desalination seems therefore the best option in this case. Even if desalination would reduce the salt content only in the outer cm of the masonry, this would probably be enough in this case. In fact the salts located near the surface are most susceptible to the RH changes of the air. Reducing the salt amount near the surface would slow down the development of the damage.

References

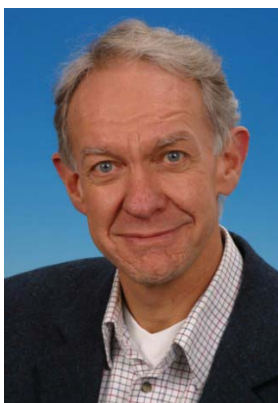
1. A.E. Charola, *Salts in the deterioration of porous materials: an overview*, Journal of the American Institute for Conservation **39**, 327-343 (2000)
2. A. Goudie, H. Viles, *Salt weathering hazard*, John Wiley en Sons, (1997)
3. A. Arnold, *Salt weathering*, 13th International Course on the Technology of Stone

- Conservation, ICCROM, IUAV, SBASVE, UNESCO (1999)
4. C.A. Price (Editor) An expert Chemical Model for Determining the Environmental Conditions needed to Prevent Salt damage in Porous Materials, Final report Project ENV4-CT95-0135, Research report n.11, European Communities (2000)
5. S.N. De Freece, J. Weber, A.E. Charola, Hygric behaviour of two of the most deteriorating salts: sodium sulfate and sodium carbonate, 6th Int. Symp. on the Conservation of Monuments in the Mediterranean Basin, L. Aires-Bairos and F. Zezza, Editors, on CD-rom (2004)
6. A.E. Charola, J. Pühringer, M. Steiger, *Gypsum: a review of its role in the deterioration of building materials*, Environmental Geology, in press
7. S. Nunberg, A.E. Charola, *Salts in Ceramic Bodies II: Deterioration due to minimal changes in Relative Humidity*, Internationale Zeitschrift für Bauinstandsetzen und Bau- denkmalspflege, **7**, 131-145 (2001)
8. B. Lubelli, R.P.J. van Hees, C.J.W.P. Groot, *Sodium chloride crystallization in a salt transporting restoration plaster*, Cement and Concrete Research **36** (8), 1467-1474 (2006)
9. Lubelli B., Sodium chloride damage to porous building materials, Phd Thesis, Delft University of Technology (2006)
10. B. Lubelli, R.P.J. van Hees, H.J.P. Brocken, *Experimental research on hygroscopic behaviour of porous specimens contaminated with salts*, Construction and Building Materials **18** (5) 339-348 (2004)



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