The influence of hygroscopic humidity from salts on moisture measurements in the case of the ‘Boskapel’ chapel in Imde-Meise, Belgium

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Abstract

When investigating moisture in building materials it is important to study both the actual and hygroscopic moisture contents (AMC; HMC) as well as the salt content. The presence of hygroscopic salts can often lead to misinterpretation of the moisture content and source. A high HMC can often be held responsible for a high AMC and result in an incorrect diagnosis and non-adapted treatment. We present a multi technique approach to investigate the presence of moisture and salts in the interior of a chapel in *Imde-Meise*, Belgium to provide advice for the optimal conservation.

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Keywords: salts; rising damp; brick masonry; hygroscopicity

1. Introduction and methodology

Several months after a treatment against rising damp damage was observed on the interior plaster of the *Boskapel* chapel in *Imde-Meise*, Belgium. To assess the role of salts and moisture in this damage phenomenon and to evaluate the success of the treatment against rising damp, approximately 100 drill samples (Ø 6mm) of plaster, brick and mortar were taken from several locations at various heights (vertically) and depths (horizontally) on 3 different occasions. The actual and hygroscopic moisture contents (AMC and HMC) were determined gravimetrically until constant weight at 60 °C for AMC and at 20 °C and 95 % RH for HMC. Ion chromatography (IC, Metrohm) was used for the quantification of the ions most commonly found in building materials (i.e. Cl⁻, NO₃⁻, SO₄²⁻, Na⁺, K⁺, Ca²⁺ and Mg²⁺). From the IC results, the thermodynamic behaviour of the ion mixtures was modelled in several climatic conditions with ECOS/RUNSALT [1, 2]. The types of efflorescence were identified by X-ray diffraction (XRD).

2. Results

The results indicated that the actual humidity (AMC) reduced with height, while vice versa the hygroscopic humidity (HMC) increased with height (illustrated in table 1). Both trends are typical in historic buildings and respectively indicate the presence of rising damp and salt deposit. Due to capillary forces of the building materials moisture is transported from the ground up. During this process ions are transported and salts are deposited at different heights depending on their solubility. In most cases mixtures with a high sulfate content are deposited lower while the more hygroscopic mixtures (which are often rich in calcium) tend to be found higher up. The accumulation of extreme salt content generally takes decades, or even centuries. Recurring exposure to rising damp leads to a buildup of salts in certain zones while the relative humidity in the environment will allow salts in solution to migrate upwards to heights way above the physical limits of pure water. The combination of the hygroscopic properties of the salts with pores in the nanometer range can also cause capillary condensation that can result in deliquescence of salts at a relative humidity below the equilibrium relative humidity (RH_{eq}) at which salts absorb moisture from the ambient air [3]. When comparing the salt contents of plaster, brick and the mortar, we can conclude that the bricks contain the lowest salt content. This can be explained by the properties of the materials with the transport of moisture and ions primarily occurring through the classical lime mortar due to the presence of, among others, finer pores that allow for a better capillary motion. In combination

Table 1. Values of the AMC and HMC, at different heights (cm) and depths (cm) for one location (P: plaster, M: mortar and B: brick).

Height	Material	Depth	AMC	HMC
248	P	0-1	10.0	21.2
		0-2	8.2	11.9
		2-5	5.9	7.0
	M	5-10	5.5	5.9
		0-2	5.3	8.9
		2-5	2.8	4.1
193	P	0-1	10.0	21.2
		0-2	7.7	11.0
		2-5	7.2	8.0
	M	5-10	5.2	5.3
		0-2	3.4	4.6
		2-5	2.6	4.3
130	P	0-2	12.8	7.6
		0-2	8.7	3.0
		2-5	6.5	2.6
	M	5-10	6.8	2.8
		0-2	6.4	3.5
		2-5	3.7	2.5
65	P	0-2	13.3	7.1
		0-2	12.4	2.9
		2-5	10.6	3.9
	M	5-10	9.3	4.3
		0-2	5.0	2.6
		2-5	2.9	2.4
17	P	0-2	14.1	7.4
		0-2	20.3	5.7
		2-5	19.1	6.0
	M	5-10	20.2	5.9
		0-2	4.8	2.5
		2-5	3.7	2.5

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with a dryer environment on the inside of the chapel and similar properties as the joint mortars, this also applies for the plaster.

In this case the HMC values are often higher than those for the AMC and overshadow the presence of the moisture source. Considering the walls have been treated against rising damp, several months after the treatment the AMC values are used as a measure to evaluate the treatment. From only the AMC values one would conclude that the treatment was unsuccessful. Knowing the HMC values, which are in line with the presence of high concentrations of salts, it becomes evident that the AMC values are partially caused by hygroscopic salts in solution within the given environment. When the relative humidity of the environment is known during sampling it is possible to determine how much of the salt is in solution. Once the RH_{eq} is surpassed the salt will keep on attracting water until it is in equilibrium with its environment. The behaviour of single salt systems is well documented and investigations have pointed to the use of the HMC for the quantification of the salt content [4-6]. In reality, however, most building materials contain complex mixtures of ions. Their hygroscopic properties are depended on the mixture composition and require thermodynamic calculations (figure 1) which do not consider kinetics, and thus are currently difficult to predict for samples collected from the field [4, 7, 8].

From the ECOS/RUNSALT model (e.g. figure 1) we can derive that when the relative humidity decreases sodium nitrate and sodium chloride will crystallize first below 65 % RH (at 5 °C). The other salts present in the mixture will stay in solution during the climatic fluctuations that may be expected in the interior of the chapel. The high relative humidity inside the chapel (higher than 65 %) has prevented damage from the latter salts by avoiding salts to crystallize. However, some damage occurred due to recrystallisation of gypsum and carbonates. The presence of moisture stains, discoloration and loss of paint layers is most likely the result of the combination of rising damp and the high HMC caused by salts in solution. The XRD analysis on the efflorescence showed the presence of sodium carbonate. Because of its high RH_{eq} (natron: 97.9 % RH at 20 °C [9]) it was the only salt that had not dissolved under the relative humidity in the interior of the chapel at the time of sampling.

Figure 1. ECOS/RUNSALT model for the crystallisation of the ion mixtures in the mortar at a depth of 1-3 cm at 5 °C, excluding gypsum and carbonates

3. Conclusions

When assessing moisture and damage to building materials hygroscopic salts can obscure the results. Here the HMC overshadows the AMC at greater heights and partly contributes to the AMC values in the lower parts of the wall. Although rising damp is obvious in this case, if the HMC and salt content were not measured the moisture source could wrongly be interpreted as horizontally penetrating moisture. For a case in which the influx of water (caused by e.g. rising damp) was stopped, the hygroscopic salts might cause high values of AMC. This study highlights the importance of analyzing several results obtained from different techniques such as the actual and hygroscopic moisture content (AMC and HMC), mineral identification (XRD) and ion contents (IC) (from different materials/heights/depths) to make a correct diagnosis on the source of moisture and the nature of the damage in order to reach an accurate conclusion and advise adapted treatments.

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