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ORIGINAL ARTICLE

The salt decay of medieval bricks at a vault in Brarup Church, Denmark

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Abstract This paper presents an investigation of the decay of bricks in the chancel vault of Brarup Church located close to the Baltic Sea at the island of Falster in Denmark. The aim of the work was to study a peculiar phenomenon in order to prescribe appropriate treatment. Although protected by a lime plaster, some bricks were pulverized up to 50 mm deep from the topside. The decay occurred in a random pattern over the structure, with undamaged bricks positioned next to deteriorated bricks. The brick structure was investigated by Mercury Intrusion Porosiometry. All bricks had a majority of pores in the range 1–10 μm, but the decayed bricks also had a fraction of pores with a diameter less than 100 nm. The difference may be due to a lower firing temperature, or it may be a consequence of the salt decay. Salt analysis proved that the deteriorated bricks were contaminated with sodium chloride, which could have degraded the brick structure. However, the powdering of the bricks may be caused by the precipitation of gypsum, which was found in the brick powder but not in the deteriorated brick itself. According to calculations with the computer program RUNSALT, the precipitation of gypsum is much influenced by the presence of sodium chloride. The gypsum precipitates due to changes in temperature between 0 and 30°C and variations in relative humidity between 75 and 95%. Seasonal climatic changes in the attic were measured to cover this interval. Perhaps sodium chloride acted as a catalyst that facilitated the accumulation and precipitation of gypsum at the topside of the bricks. A sacrificial plaster, which is the traditional treatment for salt contaminated structures, would not prevent such decay.

Keywords Salt · Decay · Brick · Climate · Vault

Introduction

The decay of bricks due to salts is a common problem in medieval Danish churches. Of particular interest is a type of damage frequently observed on top of the vaults, where some bricks have deteriorated into powder next to completely undamaged bricks. This peculiar phenomenon was investigated during a restoration campaign at Brarup Church situated at the island Falster close to the Baltic Sea. The church has a late Romanesque nave, apse and chancel and a gothic tower and porch (Fig. 1). All parts of the church were built of red brick masonry, plastered and lime washed on the inside and outside. The chancel vault has a thickness of approximately 250 mm and is contemporary with the walls (Fig. 2). The under side has fragments of wall paintings from 1300, which also suffered from salt deterioration. The topside of the chancel vault is covered with a lime plaster. The plaster had protected the brick powder in its original position, which gave an opportunity to test the salt contamination of the decayed substance. Such chances are rare because the brick powder would in many cases be lost due to prior maintenance or cleaning. The traditional way to cure the disease would be to replace the salt contaminated bricks with modern bricks. However, such intervention was not possible in this case because

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Fig. 1 View of Brarup Church from the southeast. The nave, chancel and apses are build of red brick masonry around 1300. The church is situated at the island Falster close to the Baltic Sea

the vault is decorated with lime paintings. Instead a plaster of lime mortar would be laid out on the topside of the vault to prevent further decay. But there is no evidence if this traditional method is appropriate for the conservation of salt contaminated structures. To predict the performance of a sacrificial plaster, a survey was conducted to uncover the evidence of decay. The investigation comprised salt analysis of bricks and mortar, structural analysis of the bricks and monitoring of the climatic conditions.

Background

Mechanisms of salt decay

The first case studies on the decay of medieval bricks from Danish churches were reported by Stoklund Larsen (1987). During a desalination campaign in Kirkerup Church, Klenz Larsen (1999) concluded that the damage was related to a high content of salt in the bricks, with sodium chloride as the dominant species. In Rørby Church, Klenz Larsen (2002) found that the damaged bricks were contaminated with sodium chloride, but the brick powder contained mainly sodium carbonate. Apparently this salt was the main agent of decay, as has been reported by Von Konow (1989). Binda and Baronio (1987) found sodium sulphate to be the most aggressive salt to brick specimens in a series of crystallisation tests, whereas sodium chloride did not affect the bricks at all. This was contradicted by a study at Kampischer Hof in Stralsund, where Schlütter et al. (2002) concluded that sodium chloride was the agent of decay to the bricks. An investigation of the deterioration of bricks in historic masonry buildings in northern Germany by Franke et al. (1993) found gypsum to be the main cause of damage on the outside of building structures.

Fig. 2 View of the inside of the chancel looking towards the apse. The vault is a 250 mm thick masonry structure, contemporary with the outer walls

There seems to be a general agreement about the disruptive force of sodium sulphate and sodium carbonate, but disagreement about the effect of sodium chloride to brick. Perhaps the confusion arises from insufficient information about the mechanism of decay. Both sodium sulphate and sodium carbonate form hydrates under normal climate conditions, which is not the case for sodium chloride. Hydration pressure was often referred to as the main reason for the profound corrosive effect sodium sulphate on sandstone and limestone. But studies by Rodriguez-Navarro et al. (2000) have indicated that the phase transition between mirabilite ($Na_2SO_4 \cdot 10H_2O$) and thernardite (Na_2SO_4) involves dissolution of the hydrate succeeded by precipitation of the anhydrite phase. So hydration pressure is in fact a case of crystallisation pressure for any salt. Flatt (2002) gave a theoretical deduction of the phenomenon. He outlined the relationship between the super saturation of the salt and the pressure it would impose on the pore walls. The degree of super saturation depends on the salt species and the pressure of the pore water, which relate to the average pore radius. In a work by Rijniers (2004) the super saturation was measured for both sodium chloride and sodium sulphate. For materials with a tensile strength less than 3 MPa, only pores at diameters less than 5 nm would generate damage by precipitation of sodium chloride, whereas crystals of sodium sulphate would grow in pores at diameters less than 100 nm. According to these results the crystallisation pressure of sodium chloride would not be able to disrupt coarse materials like brick.

The thermodynamic considerations all assume equilibrium, which may not apply to the dynamic conditions of the real world. In laboratory tests, Nielsen (1991) demonstrated that both the thermal and the hygric expansion increase remarkably, if the brick is contaminated with sodium chloride. When exposed to fluctuating climatic conditions, the mechanical stress caused by the strain would lead to a degradation of the brick structure. Wendler (2002) reported similar results from laboratory measurements on salt loaded brick samples in periodically changing relative humidity (RH). In this case the expansion was partly reversible, but the strain accumulated over many climate cycles. This phenomenon was explained by the formation of crystals in the narrow pores that would not dissolve during wetting phases. Even if the dynamics of crystallisation is not yet fully understood, it is evident that the occurrence of salt damage does not only depend on the salt species and the porous material involved. The climatic conditions also play a decisive role. To specify appropriate preventive protection of salt contaminated structures in real life, all parameters must be taken into consideration.

Properties of mixed salt solutions

The deterioration of bricks may also arise from salt mixtures. In systems of three or more ions the solubility and crystallisation humidity of the individual salts is usually not the same as for the single salt. However, the thermodynamics of mixed salts is quite complicated, and until recently, it was not straightforward to determine the properties of a given combination of ions. For the study of seawater evaporates, the solubility of sodium chloride and other ions have been studied by Harvie and Weare (1980). Price and Brimblecombe (1994) introduced the problems related to mixed salt solutions to conservation science. They pointed out that the solubility of gypsum is increased up to four times when mixed with sodium chloride. At the same time the crystallisation humidity is lowered from close to 100% RH down to approximately 75% RH for a saturated solution. But they gave no indication of the influence of temperature. Steiger and Zeunert (1996) measured the osmotic coefficients for several solutions with three ions and published a series of solubility diagrams for various salt solutions with four ions. But they did not include the system Na–Ca–Cl–SO_4–H_2O in their work. The computer program ECOS was developed by Price (2000) to calculate the crystallisation of any salt mixture, and its function was later improved with the program RUNSALT developed by David Bionda. RUNSALT is protected by copyright (2002–2005) and it is available for free at http://www.ftk.id.arch.ethz.ch. This program enables the user to determine the precipitation of salts from any mixture of sodium, potassium, magnesium, calcium, chloride, nitrate and sulphate ions. The computer program was used to estimate the influence of temperature and RH on the precipitation of gypsum when mixed with sodium chloride. For a mixture of 1 mol of $CaSO_4$ to 20 mol of sodium chloride, the precipitation at different temperature is shown in Fig. 3. The gypsum starts precipitating at approximately 95% RH, and the crystallisation gradually increases with falling RH until 75%, where all gypsum will be solid crystals. At 75% all halite precipitates, but this is not shown in the diagram. The influence of temperature is shown in Fig. 4, at a fixed 85% RH. The amount of precipitated gypsum rises from 0 mol at approximately –4°C to 0.7 mol at 30°C. This fits well with the fact that the solubility of pure gypsum rises with falling temperature. Below 0°C the formation of gypsum is inhibited, and instead mirabilite ($Na_2SO_4{\cdot}10H_2O$) starts precipitating. At –20°C most of the sulphate will be precipitated as mirabilite. At a relative humidity below 75% RH the precipitation of halite (NaCl) will be dominant at any temperature. As stated by Rijniers (2004) the pressure in the capillary pores will affect the precipitation, but this phenomenon becomes very complex with mixed salt solutions and it is not investigated further in this paper.

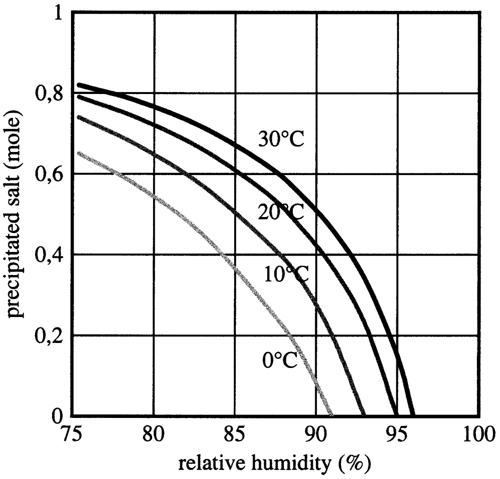

Fig. 3 The precipitation of gypsum from a mixture of 1 mol of $CaSO_4$ to 20 mol of NaCl in the interval 75–100% RH at fixed temperatures as indicated in the diagram. Calculated by the computer program RUNSALT

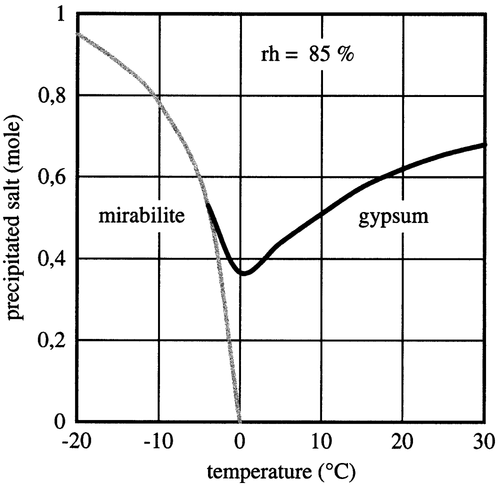

Fig. 4 The precipitation of gypsum from a mixture of 1 mol of $CaSO_4$ to 20 mol of NaCl in the interval –20 to 30°C at a fixed relative humidity at 85% RH. Calculated by the computer program RUNSALT

Measurements and results

Salt analysis of bricks and mortar

An examination of the topside of the chancel vault in Brarup Church revealed that some of the bricks were deteriorated up to 50 mm deep. The damage included approximately 5% of the bricks. The decay was unevenly distributed over the structure with undamaged bricks and deteriorated bricks positioned next to each other in a random pattern. The decay was not always visible, but when knocking gently at the surface of the plaster, a hollow sound indicated a cavity. At one place samples of approximately 1 g were taken from the mortar, the brick powder and the remaining solid brick below the brick powder. The samples were analysed for the content of water-soluble salts (Fig. 5). The lime mortar had only minor salt deposits, less than 0.5% by weight in total. The solid part of the damaged brick was contaminated by 1.6% by weight of salt, with sodium chloride as the dominant species. The brick powder contained the same amount of sodium chloride as the solid part of the brick, but also had a remarkably high concentration of sulphate ions. In all samples the content of potassium, magnesium and nitrate was rather low. The distribution of sodium chloride within the bricks was measured on profiles drilled from the topside of the vault. Powder samples were drilled with a 6 mm drill to a depth of 190 mm from two damaged bricks marked I and II and one undamaged brick. All samples were analysed for the content of sodium and chloride ions (Fig. 6). The damaged bricks contained sodium chloride in considerable concentrations of almost 3% by weight at the upper surface, gradually reducing to 0.5–1% by weight in depth. The undamaged brick had less than 0.5% by weight in all samples.

A pile of broken bricks was deposited in the southeast corner of the vault, covered with a thick layer of clay. The bricks did not have any lime mortar on the surface, so presumably they have never been a part of the structure. A C-14 analysis was made on a twig found in the clay covering. The lump of wood originated from around 1300 AC, so it is likely that the bricks have been left over from the construction of the vault. This gave an opportunity to test original bricks that have been well protected against external influence during the centuries. Samples were taken from a hard fired brick, an unfired clay brick and from the clay covering, and analysed for the content of water-soluble salts (Fig. 7). The clay brick contained a

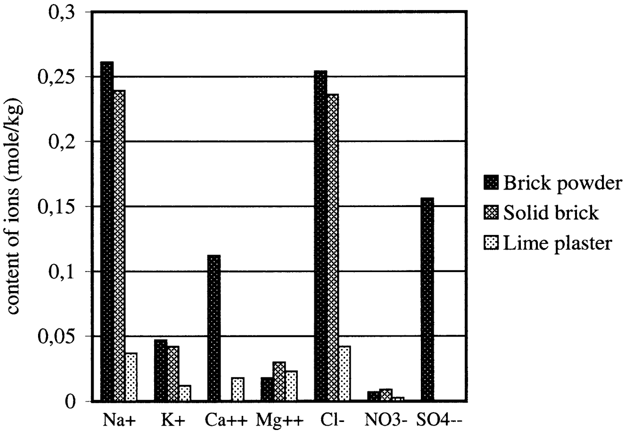

Fig. 5 The salt content in samples of mortar and decayed brick taken from the topside of the vault. The content of sulphate ions was below the detection limit for solid brick and mortar

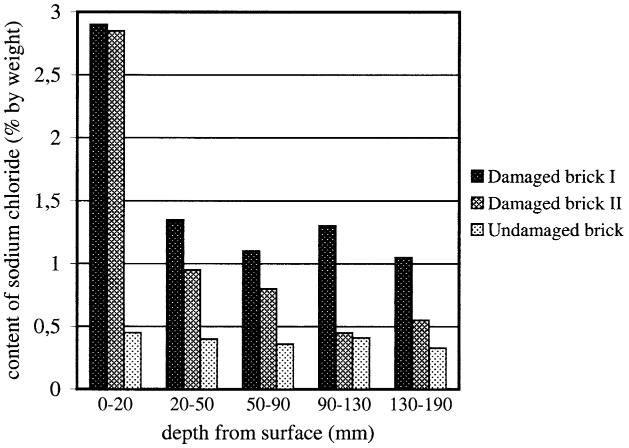

Fig. 6 The salt profiles of sodium chloride for two damaged and one undamaged brick drilled from the topside of the vault

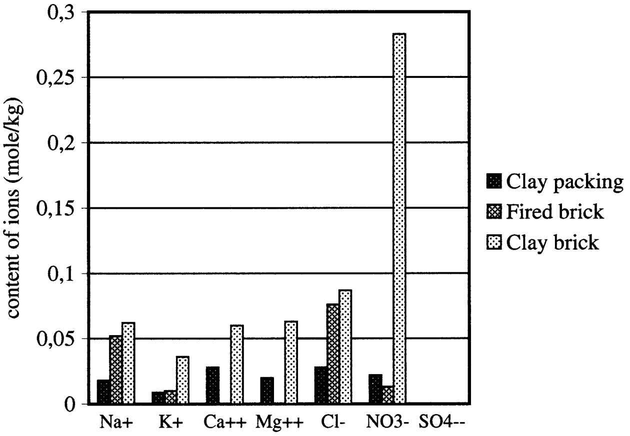

Fig. 7 The salt content of clay and brick samples found above the vault. The content of sulphate ions was below the detection limit

considerable amount of nitrate, probably of organic origin, but only a moderate concentration of other salts. The clay packing contained almost no salts, and the brick from the pile only had a little sodium chloride. In all samples the content of sulphate was below the detection limit.

The salt analysis was made on aquarious extracts of ground samples. Sodium and potassium was measured by a flame photometer produced by Evans Electroselenium Limited. The salt extraction was vaporised by compressed air into a gas flame, whereby the metal ions emitted light at a wavelength specific for the individual metal, and at intensity proportional to the number of ions. The light passed through a filter onto a photocell, and the signal was transformed to a reading on a galvanometer and translated to ion concentration by a calibration curve. Calcium, magnesium, chloride, nitrate and sulphate ions were measured by a test kit produced by Dr. Lange GmbH. The salt extraction was prepared with various chemicals to produce a colour reaction, specific for each type of ion and proportional to the ion concentration. The intensity of the colour was measured with an electronic photometer (type L-20) with a light beam that passed through the cuvette and a filter onto a photocell. The signal was transformed to a digital reading by the apparatus using built in calibration curves. The samples were also screened for the content of carbonate ions.

Pore structure of the bricks

Samples for structural analysis of the bricks were drilled with a 40 mm core drill 100 mm deep from the topside of the vault. Samples were taken from one undamaged and one decayed brick. Prior to the drilling, the brick powder was removed from the decayed brick, so only solid brick were analysed. From the deepest end of the cores, 10 mm were used for thin sections and 10 mm for pore size measurements. The pore size distribution for the decayed and the undamaged bricks was measured by MIP (Mercury Intrusion Porosiometry (Fig. 8). For each sample two measurements were performed. The diagram represents the average values. The undamaged bricks and the damaged bricks both had a majority of pores in the range of 1–10 µm. In the damaged bricks there were also a considerable fraction of pores in the range 0.01–0.1 µm.

Thin sections were made of the drilled core samples from each brick to study the pore structure (Figs. 9, 10). Both bricks contained white lumps of quartz grains market with a ‘Q’. The undamaged bricks had a homogeneous glass matrix market ‘M’ with a coarse pore structure (Fig. 9), whereas the glass matrix of the damaged bricks was much less coherent and the pores were finer (Fig. 10). The difference in the brick structure may arise from variations in the firing temperature. In medieval times it was not possible to control the temperature in the firing kilns as accurate as today. The uneven quality of the bricks was apparent when examining colours of the left over bricks found in the attic. The colours varied from light brown over bright red to purple and almost black. The colours indicated the firing temperatures to have been somewhere from 800 to 1,100°C (Schumann 1997).

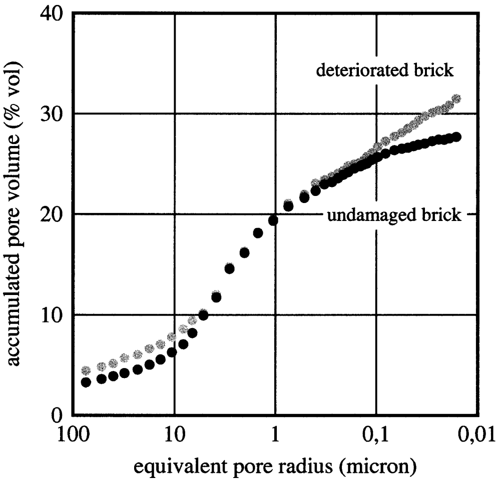

Fig. 8 The pore size distribution of a damaged and an undamaged brick, measured by Mercury Intrusion Porosiometry (*MIP*). The damaged bricks have a larger fraction of pores in the range 0.1–0.01 µm than the undamaged bricks

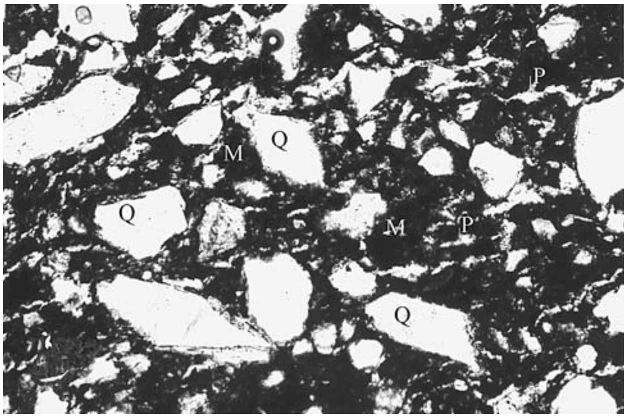

Fig. 9 Polished thin section of an undamaged brick. The section is 2 mm wide. The white lumps (*Q*) are quartz sand grains. The black glass matrix (*M*) has a coherent structure and the pores (*P*) are coarse

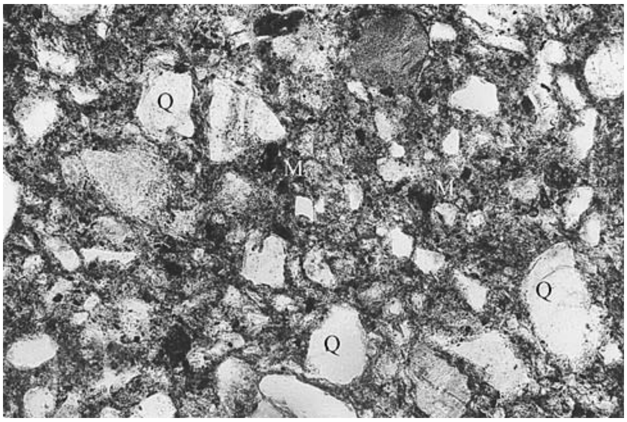

Fig. 10 Polished thin section of a damaged brick. The section is 2 mm wide. The white lumps (*Q*) are quartz sand grains. The glass matrix (*M*) is not coherent and the pores are fine

Climate measurements

The climate in the attic and in the nave was monitored over a period of 1 year. Temperature and relative humidity was measured every second minute and the average values were stored by the data logger every hour. The sensors were Vaisala HMP35AC connected to a CR10X datalogger from Campbell Scientific. An example of the data for the month of May is shown in Fig. 11. The variations in temperature are the same as in the outside air, but the RH is much more stable. When the outside RH drops from close to 90 to 60% or lower, the RH in the attic remains moderate. The results for the whole year of 1999 are displayed in Figs. 12 and 13 in a slightly different format. In these diagrams every point represents both temperature and RH as the running average of 24 h, so the value for every hour is the average of the 12 h before and the 12 h after. The grey points indicate the climate in summer (April–September) and the blacks points show the winter climate (October–March). In the attic, the RH is 70–90% most of time during summer and the temperature is between 10 and 20°C. In winter, the temperature is 0–10°C and the RH is 80–100%. There is a clear shift in temperature from summer to winter, whereas the RH is not so much influenced by the season. In the nave the temperature is 10–25°C over the summer and the RH is 50–80%. During the winter the temperature goes from 5 to 20°C and the RH is still between 50 and 80%. The curved shape of the cluster is due to the influence of the intermittent heating on the indoor climate. When the air is heated from 5 to 18°C, the RH drops from around 80 to 50%.

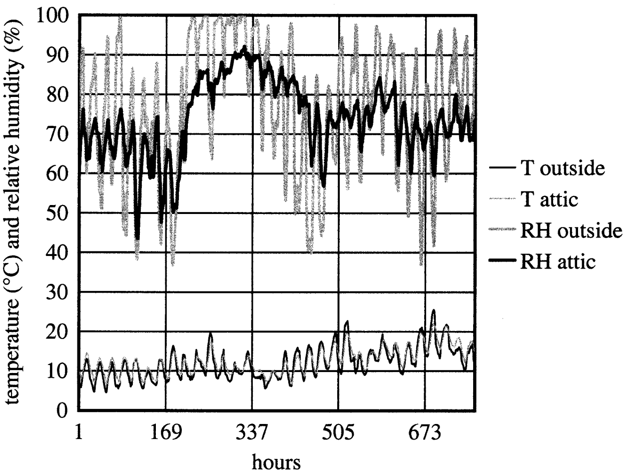

Fig. 11 Climate measurements in the attic and outside during May. Measurements were taken every 2 min, and each point represents the average of 1 h. The RH in the attic is much more stable over the day than outside, but during the week the RH follows the outside average

Discussion

The combination of a high salt content and a fine pore structure seemed to be crucial factors for the decay of bricks in the vault in Brarup Church. The question was, if these two characteristics were independent, or if the one was a consequence of the other. One possibility would be that the bricks suffered from two stages of deterioration. The first stage was a general disruption of the glass matrix leading to degradation of the brick structure observed at the thin sections and leaving a new fraction of pores in the range 0.1–0.01 μm. The second stage was a total loss of coherence of the fractured glass matrix and a change of the physical condition into

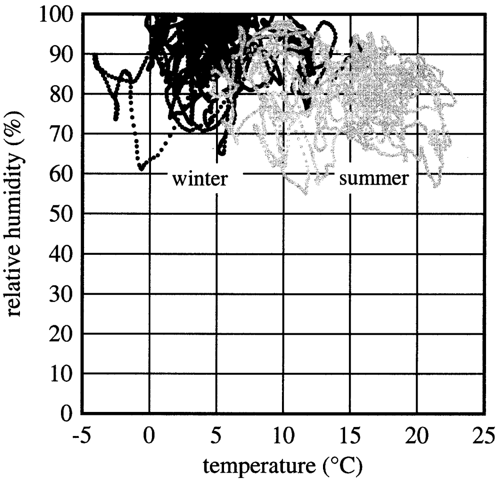

Fig. 12 Climate measurements in the attic over 1 year. Each point represents the running average of 24 h of temperature and relative humidity. The *grey points* are in summer and the *blacks points* are the winter season. The *two clusters of points* indicate the seasonal changes in RH and temperature

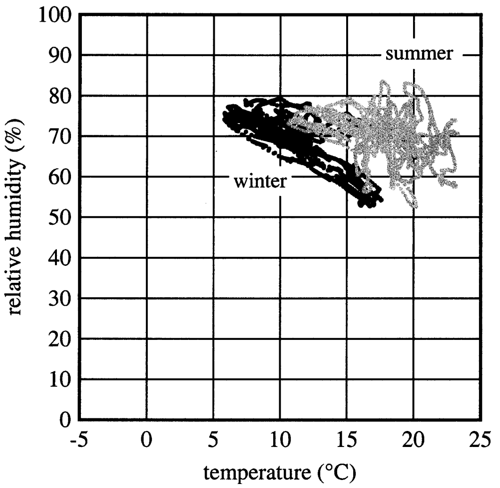

Fig. 13 Climate measurements in the nave over 1 year. *Each point* represents the running average of 24 h of temperature and relative humidity. The *grey points* are in summer and the *blacks points* are the winter season. The *curved shape* of the winter cluster illustrates the influence of the intermittent heating

ceramic powder. Both stages were present at each of the damaged bricks, whereas neither of the stages was observed at the undamaged bricks. For this theory to work, there had to be a good reason for the uneven distribution of sodium chloride. The bricks found above the vault contained a small amount of sodium chloride; so all bricks must have been slightly exposed to salt even before the construction of the vault. The undamaged brick in the vault held the same concentration of salt (0.3% by weight) evenly distributed over the section, so this salt concentration seemed to be a general starting position for all bricks. Such degree of salt infection was safe for any brick, since there was no evidence of decay. The damaged bricks contained much more sodium chloride, up to 1.6% by weight for both the solid brick and the brick powder.

To explain the uneven distribution of the salt it would be obligate to locate the source of the ions. The vault may have been contaminated with sodium chloride during construction, if the salt was mixed into the mortar for frost protection. Alternatively, the sodium chloride may have been supplied to the vault from sea spray if the building was left without a roof for a period of time. Once the salt had entered the porous structure of the bricks and mortar joints, it would have redistributed within the vault and concentrated in a few bricks. Salt preserved foods may be another possible source, stored away in the loft during episodes of war. In the Baltic region, herring was a major source of nutrition for many centuries, packed and kept in barrels with lots of salt. A few leaking barrels would account for the uneven salt contamination. Once the salt had entered the porous interior of each individual brick, the decay was initiated by the climatic conditions to which the vault was exposed. The variations in relative humidity played an important role for the degradation process. Under stable conditions sodium chloride would stay in solution if the RH was above 76% or remain precipitated and do no harm if the RH was below 76%. The climate recording showed that most of the winter the RH in the attic was above the crystallisation humidity of sodium chloride. But in summer, the natural climate in the attic was quite unstable, and many climate cycles passed the crystallisation humidity of sodium chloride. Consequently, the precipitation of sodium chloride was likely to be the reason for the decay of the salt contaminated bricks. However it gives no explanation for the occurrence of the two phases of degradation.

Consider again the salt analysis of the pulverized brick that was found beneath the mortar (Fig. 5). This powder had the same concentration of sodium and chloride as the solid brick, but it also contained 0.15 mol/kg of sulphate ions. The average concentration of sulphate in the bricks was found to be below the detection limit of 0.01 mol/kg, so where did the high concentrations of sulphate in the powder come from? In some situations the sulphate would originate from air pollution, when sulphur dioxide was deposited from acid rain at the outside of the building. The combustion of fossil fuel was not likely to be the source here, but perhaps the sulphate originated from the firing of the bricks, if peat was used as fuel. However this did not explain why the sulphate accumulated in the brick powder. The powder also contained calcium ions in approximately the same concentration, so the sulphate was likely to be precipitated as gypsum. The gypsum was formed by the chemical reaction of sulphuric acid and lime particles in the clay or lime from the mortar. This mineral is well known for its corrosive effects on limestone, sandstone and ceramics. However, gypsum is not hygroscopic and would therefore not be able to migrate, unless there was a source of liquid moisture like rising damp or driving rain on a facade. But in a solution of sodium chloride the crystallisation humidity for gypsum would be lower than the usual 100% RH. In the case of Brarup Church, perhaps sodium chloride acted as catalyst that enabled the gypsum to dissolve, migrate and finally accumulate at the top end of the brick. The system of $Na–Ca–Cl–SO_4–H_2O$ was sensitive to variations in both temperature and relative humidity in the attic, so over the centuries, seasonal changes in temperature and RH at the topside would have facilitated the precipitation of gypsum. This assumption was in fact contradicted by the climate measurements. Over the year, the average RH below the vault was much lower than above the vault, so one would expect the evaporation from the vault to take place mainly in the nave. As a consequence, the gypsum would concentrate in the lower end of the bricks and not at the topside. But there were no indications of such damage to the end of the bricks faced downwards. The reason may be that the influence of the heating was recent, not much more than 50 years of age. For the first many centuries the church was unheated or only heated to lower temperatures than today. Without heating the nave and chancel would have been more humid all year round, but there are no historic climate records from this church or any other medieval building. In the attic the climate in historic time must have been quite similar to our days, because it was mainly influenced by the outdoor climate.

The results presented in this case study are in some ways similar to the work of Lubelli et al. (2004). Based on observations on a Dutch church, they suggested that the formation and precipitation of gypsum would be catalysed by a solution of sodium chloride. Two different types of decay was observed on the brick surface, referred to as powdering and blistering. The former was related to the presence of sodium chloride and the latter to the precipitation of gypsum. However, the two phenomena were not both found at the same brick, so the case was not identical to the findings in Brarup Church. Though supported by such independent observations, the theory of a decay mechanism evolving in two stages due to the action of two different salts is not fully justified. If the sodium chloride were supplied from salt preserved foods at specific areas, it would most likely have redistributed within the vault or at least have spread to the neighbour joints and the plaster covering the vault. But no salt was found in the plaster or the mortar joints. The reason for this could be that the salt concentrated in some bricks, because they had more capillary pores that would attract the salt solution. The capillary pressure under a meniscus of water in pores at diameters from 0.1 to 0.01 μm will be in the range –1.5 to –5 MPa. In pores with diameters larger than 1 μm, the capillary pressure will be close to 0. As a consequence of the pressure difference, the bricks with small pores were able to extract liquid from the mortar joints or even the neighbour bricks. Over the centuries, variations in the pore structure of the bricks have facilitated the uneven distribution of salt in the vault. The small pores were characteristic for these bricks, introduced due to a lower firing temperature. According to this theory, the reason for the decay was the combination of an initial poor quality of some bricks and the subsequent contamination with sodium chloride, followed by centuries of natural variations of the climate in the attic. Such processes are very difficult to simulate in laboratory experiments, and computer programs are still not advanced enough to take all parameters into account. Hopefully the study of degradation phenomena in real buildings and monuments will bring further evidence of decay of bricks due to salt mixtures.

Conclusions

The results from Brarup Church indicated that the precipitation of gypsum and sodium chloride was the reason for the decay of bricks in the vault. Both the powder and the remaining solid parts of the damaged bricks were contaminated with sodium chloride, but the brick powder also had a considerable concentration of calcium and sulphate ions. Calculations carried out with the computer program RUNSALT showed that gypsum would precipitate in the range 75–100% RH when mixed with sodium chloride. The amount of gypsum precipitated at a fixed relative humidity is dependent on temperature. Hence, the precipitation of gypsum was facilitated by the natural climate changes, when mixed with sodium chloride. The climate of the attic was mainly influenced by the outside climate, but the daily variations were levelled out. Seasonal changes were in the range 70–100% RH and 0–20°C, which coincided with the precipitation range of the salt mixture. The gypsum probably originated from the firing of the bricks and was mobilised by a subsequent contamination of sodium chloride. It was not possible to conclude, why only a few bricks were deteriorated. One possible explanation is that only the poorly fired bricks were affected by degradation, because they have more capillary pores, which accumulated more salt than the hard fired bricks. Another theory suggests that the decay started due to salt wasted from salt preserved foods in certain areas of the vault. The decay evolved in two stages, where the glass matrix of the bricks gradually degraded and finally pulverized. The vault was covered with an original lime plaster, so the decay was not visible and the deterioration process may have progressed slowly during the 700 years lifetime of the church. Apparently, a sacrificial plaster did not prevent such degradation in the long run. Only climate control with the RH constantly below 75% RH would inhibit the crystallisation of any salt from the mixture.

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