Salt decay of Morley limestone

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Salt weathering is one of the main causes of decay of natural stone, and by consequence a major problem to the conservation of cultural heritage. In the present case, the performance of Morley limestone from the Département Meuse, France, as a replacement stone under salt-loaded conditions is evaluated. Morley limestone was used in the Netherlands as a replacement stone for sandy Eocene Belgian limestones (Gobertange, Lede).

Key words: Morley limestone, salt weathering, Pieterskerk, Leiden

1 Introduction

Salt weathering is one of the main causes of decay of natural stone, and by consequence a major problem to the conservation of cultural heritage. In the present case, the performance of Morley limestone as a replacement stone under salt-loaded conditions is evaluated. Morley limestone is a white to greyish limestone, quarried up to the 1970's in the Département Meuse in France. In the second part of the 19th century, limestones from northern France have been introduced in the Netherlands, amongst others as replacement stones for white Belgian sandy limestones (e.g. Slinger et al. 1980, Nijland et al. 2007). Widely used French limestones include St. Joire, Savonnières, Euvile, Massangis / Vaurion and Coutarnoux.

The Morley limestone has been as stone for newly constructed buildings since the 1980's, as well as, more rarely, a replacement stone. Newly constructed buildings include Hotel l'Europe and the city theater in Amsterdam (both 1920's). Durability in Dutch climate has been appreciated variably. According to Slinger et al. (1980), Morley limestone was mainly used for indoor purposes, inline with Vrind et al. (1941) who did not consider Morley a durable stone at all. Lijdsman (1944) considered the soft not suited for outdoor use, but thought the varieties dur and demi dur to be weather resistant. Outdoor durability of Morley limestone in Dutch climate has been evaluated in the 1950's (Ratiobouw 1956). At a mausoleum of a cemetery in Haarlem, placed in 1898, Morley showed moderate weathering after about 60 years; at the Verenigingsgebouw on Nijmegen's Charlemagne square, constructed in 1914, was in good condition after over 40 years. As a replacement stone in restorations, the Morley limestone was used on both major churches in the city of Leiden, viz. the Hooglandse or St. Pancras' Church and St. Peter's Church (Pieterskerk), at the beginning of the 20th century.

St. Peter's Church, from which the Pilgrim Fathers left for America, was established around 1390, the choir and nave being finished in 1413 and 1450, respectively, whereas the transept was built between 1450 and 1600; in 1512, the tower of the church collapsed, damaging the western part of the nave, that was given a new façade, without tower, in 1513 – 1518 (Van den Berg 1992). Prior to the current restoration completed in 2009, the church was restored during the end of the 19th and the first half of the 20th century. During these restorations, Morley limestone has been introduced on the church. Archival sources document the use of Morley limestone in 1894, 1907-1914, 1920's and again in 1940 (Lambrechtsen 1999, Veerman et al. 2001). Morley limestone was used, amongst others, for traceries, in wall cladding, etc.

After 80 – 100 years, severe damage was observed on montants in the southwesten and notably northwestern façades of the transept of St. Peter's Church. Contrary to what might be expected, most damage was present on the interior sides of the montants. Damage consisted of severe scaling, flaking and powdering of the limestone (Fig. 1), some of those showing white efflorescence. Remarkably, some montants directly adjacent to each other show severe damage, whereas others do not.

Figure. 1: Example of severe scaling, flaking and powdering of Morley limestone, west façade of the south transept (situation 2003, prior to restoration).

2 Analytical methods

Powder samples for determining actual and hygroscopic moisture contents have been collected by dry drilling at different depths. Moisture contents have been determined according to Dutch standard NEN 2778:1991; hygroscopic moisture contents have been determined at 20°C, 96% RH. In addition, efflorescences have been collected to determine the mineralogical composition of salts present. These have been determined by XRD.

One montant has been removed entirely (Fig. 2, 3), to obtain specimens for study by polarization-and-fluorescence microscopy (PFM), the determination of hygric behaviour (water absorption coefficient and drying behaviour, both determined gravimetrically at 20°C, 65% RH), and the determination of pore size distributions by mercury intrusion porosimetry (MIP).

Figure 2: Montant of Morley limestone removed from St. Peter's Church for laboratory investigation, with the interior side suffering salt damage at the bottom. Inset shows the original position of the montant.

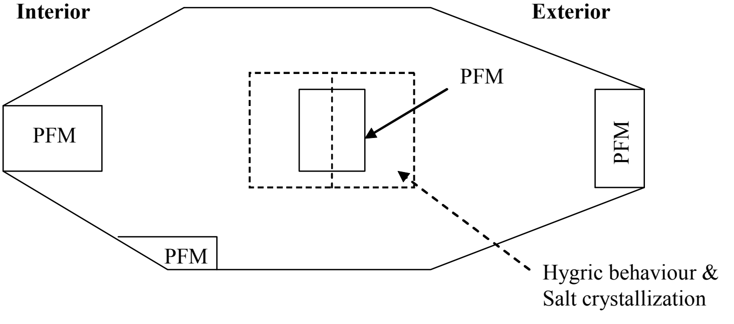


Figure 3: Schematic cross section through the montant in figure 2, showing the location of thin sections (PFM) and samples for determining hygric behaviour and salt crystallization tests. Samples come from the same cross section.

3 Microscopy and X-ray diffraction

The Morley is an oolithic limestone, with minor bioclasts, and a macroporosity estimated at 20 vol.% (Fig. 4). Ooliths and bioclasts are cemented by carbonate mud partly recrystallized to microspar. The amount of carbonate cement / microspar is about 10 vol.%. Original sedimentary bedding is well developed (Fig. 5). In the montant showing damage, the bedding is oriented perpendicular to the façade (i.e. parallel to the section in figure 3). In the damaged zones, microcracking and scaling occurs parallel to the original sedimentary bedding, with powdering occuring over the surface (Fig. 6). No formation of gypsum has been observed in thin sections of the montant in figure 2. X-ray diffraction analysis (XRD) of limestone powder sampled from the interior nose of the montant shown in figure 2 indicates only the presence of halite, NaCl. A powder sample from the interior surface of another, less deteriorated montant also shows the presence of a minor amoutn of gypsum, $Ca_2SO_4 \bullet 2H_2O$. Halite is, however, believed to be the main salt responsible for the observed damage.

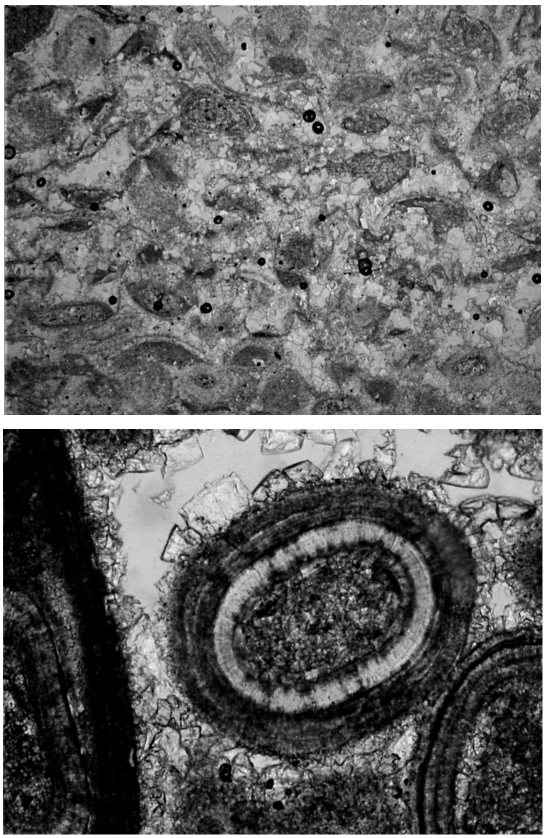


Figure 4: Microphotographs showing an overview of the microstructure in the core of the montant (view 5.4 x 3.5 mm) and detail of ooliths near the interior nose of the montant (view 2.8 x 1.4 mm) in Morley limestone.

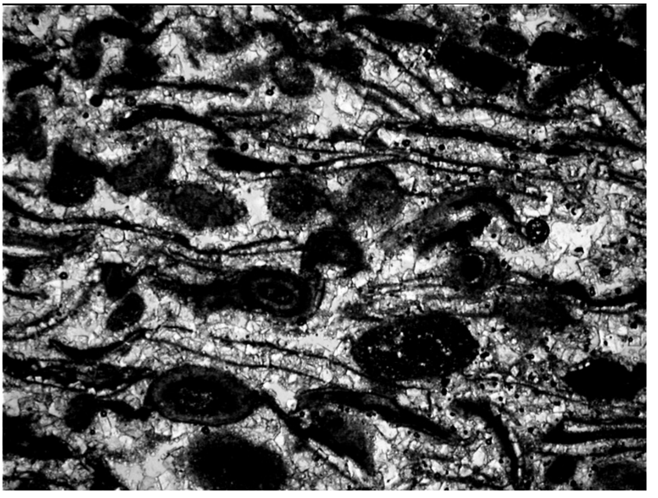


Figure 5: Microphotograph illustrating sedimentary bedding in damaged Morley limestone (thin section near the interior nose of the montant, view 5.4 x 3.5 mm).

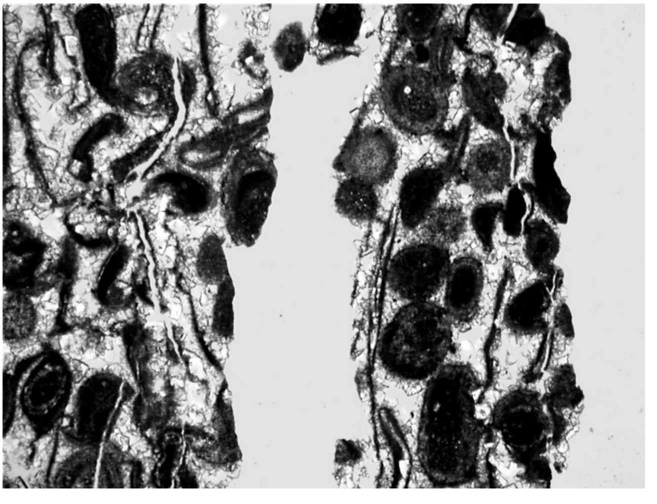
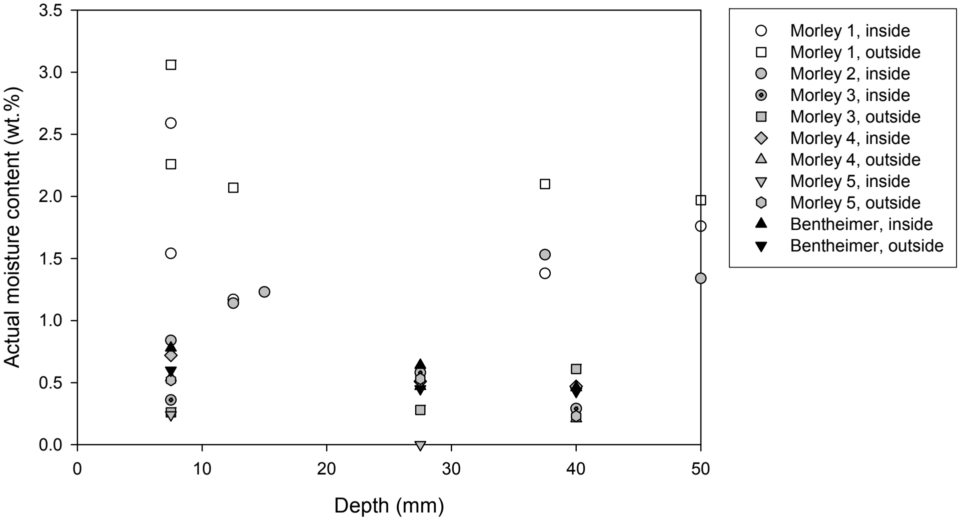


Figure 6: Microphotograph showing microcracking and delamination parallel to the bedding from the lower interior corner of the damaged montant (view 5.4 x 3.5 mm)

4 Actual and hygroscopic moisture contents

Actual and hygroscopic moisture contents have been determined for both interior and exterior parts of several montants in Morley limestone, as well as, for the purpose of comparison, of a montant composed of Bentheim sandstone with similar exposition and



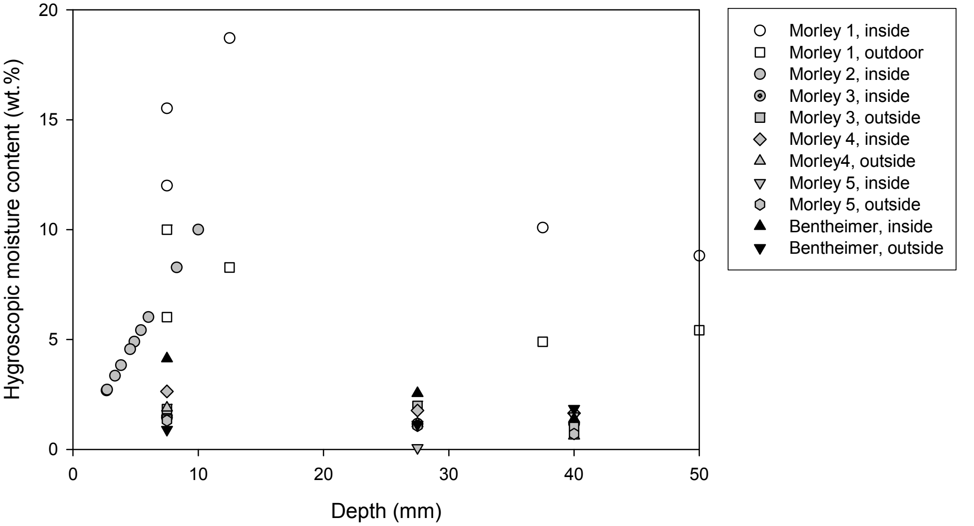


Figure 7: Variation of actual (above) and hygroscopic, at 96% (below) moisture contents with depth for deteriorated Morley limestone (white symbols), not to scarcely deteriorated Morley limestone (grey symbols) and not deteriorated Bentheim sandstone (black symbols).

orientation. The latter natural stone has been used elaborately in the Netherlands, from the 11th century onwards in the east of the country, and from 1450 onwards in the centre and western parts of the country (e.g. Nijland et al. 2003, 2004). The hygroscopic moisture content, determined at 96% RH, provides an indication of the total amount of

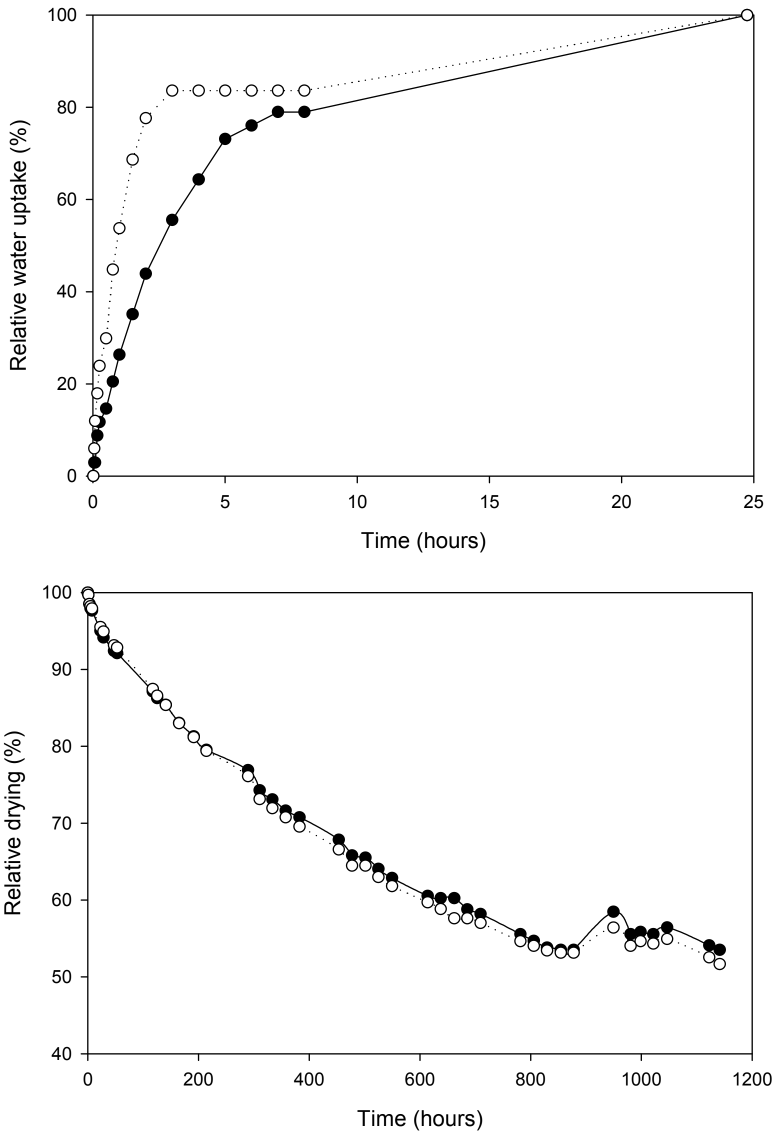


Figure 8: Relative water uptake and drying of Morley limestone (from the interior part of a montant; test in duplo).

(hygroscopic) salts present. Results are given in figure 8. These show considerably higher actual and hygroscopic moisture contents for the deteriorated montant compared to both not or amply deteriorated Morley montants. Moisture and (indicative) salt contents in the latter are comparable to that of the montant in Bentheim sandstone. In case of the deteriorated Morley montant, actual moisture contents are lower, hygroscopic moisture contents are higher in the parts of the montants in the interior of the church than in parts exposed outside.

5 Hygric behaviour and pore size distribution

Water absorption and drying curves have been determined for two samples cut from the internal part of the deteriorated Morley montant (Fig. 9). Those yield water absorption coefficients of 0.053 and 0.044 kg m^{-2} $s^{-0.5}$. On one of the samples, salt efflorescence occurred during drying, apparently from salt already present in the sample. Pore size distributions by MIP have been obtained for both undamaged Morley from the internal part of the montant, and from deteriorated Morley from the interior nose of the montant. Results are given in figure 10. Both show relatively few small pores, -implying relative fast drying-, and a slight shift to larger pores and total porosity with deterioration.

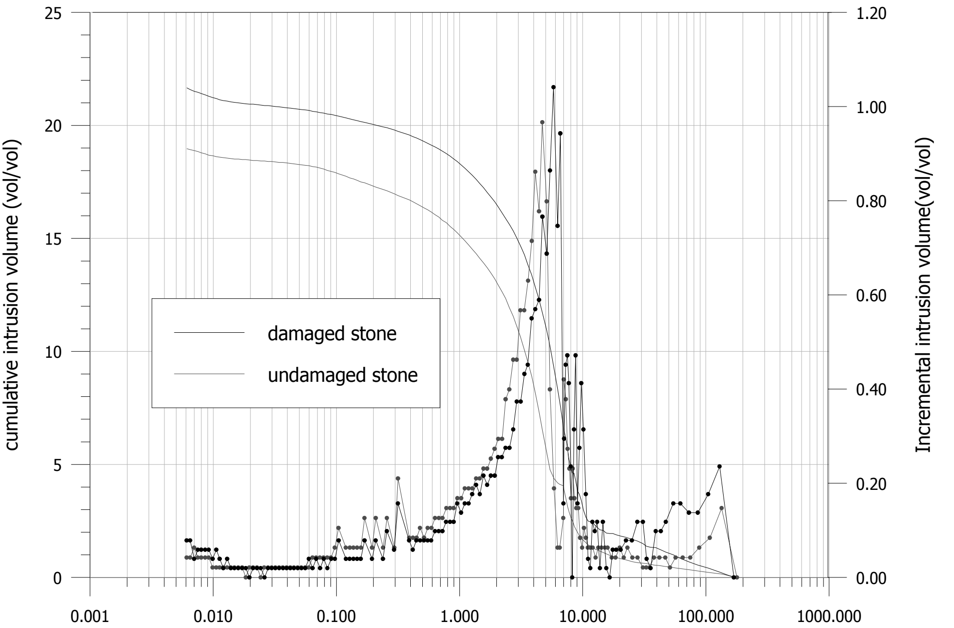


Figure 9: Pore size distributions (diameter in micrometre) for deteriorated and not damaged Morley limestone, as obtained by MIP.

6 Discussion and conclusion

Morley oolithic limestone from the Département Meuse has been used for both newly constructed buildings as well as replacement stone in the Netherlands during the last decade of the 19th century and first decades of the 20th century. At several buildings from this period, Morley limestone is still in fairly good condition. Morley at the walls of St. Peter's Church, Leiden, is generally also in good condition. Montants of Morley limestone at this church, however, show severe damage on the interior side, due to action of NaCl, which may be present in moderately high amounts near the surface. The exterior side generally shows no or very limited damage, and low salt contents, comparable to those of montants of Bentheim sandstone with the same exposition. The source of NaCl is unclear, infiltration of water with salt derived from sea spray or past cleaning operations of the interior to remove plasters, paint or lime wash may be options.

The question arises why damage occurs at the interior. Apparently, moisture and salt transport occur in inward direction, in response to the indoor climate. Indoor climate will also strongly influence damage development. Repeated RH cycles in which the equilibrium RH of NaCl (c. 75%) is passed, in response to the indoor climate, are the most likely mechanism of salt accumulation and resulting damage (cf. Lubelli 2006). The damage process due to NaCl may, in case of Morley limestone, be self-accelerating, given the slight shift to larger pores accompanying the damage.

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