Understanding historic mortar and their variations – a condition for performing restorations with traditional materials

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Abstract
In order to design a restoration mortar with properties and composition similar to the original mortar, it is important to analyze the historic mortar in several ways. A combination of analyses give information about the mixing ratio between binder and aggregates, chemical composition of the mortar, additives, tool marks, application technique etc. This paper shows the variations in Swedish medieval lime mortars with a high rate of binder. By analysing historic mortar with a combination of ocular investigations, microscopically studies of thin section specimens, Scanning Electron Microscopy and X-Ray Powder Diffraction, all the information needed for designing a restoration mortar, with composition and properties similar to the historic mortar, is gained.

Keywords: lime mortar, thin section, SEM, XRD

1 Introduction

When adding new materials in conservation and restoration of an architectural heritage, the new materials should be compatible with the old materials in order to preserve them. Old mortar remaining on historical buildings is an important source of knowledge that can be used in the restoration work. In order to design a restoration mortar with properties and composition similar to the original mortar, it is important to analyze the historic mortar in several ways. A combination of analyses gives information about the mixing ratio between binder and aggregates, chemical composition of the mortar, additives, tool marks and application technique [1]. This paper show the difference between several medieval lime mortars from different regions of Sweden. The geological variation of the country is reflected in the historic mortars. Only by knowing and understanding the differences they can be restored with traditional mortars with similar properties.

A simple ocular examination can show:

- If the mortar were made for joints or plaster, the colour of the binder.
- If it is a mortar rich in lime or not.
- The content of small or large particles in the aggregate.

- Impurities or additives such as crushed bricks, coal or pieces of wood and fibres of different kinds.
- Tool marks, lime wash residues and residues of other paint

Optical and spectroscopic methods, such as Scanning Electron Microscopy (SEM), optical microscopy analysis of thin section samples and X-ray powder diffraction analysis (XRD), can be used to investigate the following important aspects more in detail:

- The type of binder, such as clay, lime, hydraulic lime or cement, used in the mortar.
- The geographic origin of the raw material used for lime burning.
- The lime slaking method and storing of the lime putty [2].
- The origin of the aggregate, their mineral composition and particle size distribution.
- Any additives used when making the mortar.
- The methods used in the application and working of the plaster, by traces of tools.
- The number of lime wash layers applied to the surface.
- The mixing ratio of the mortar.
- The pore structure and durability of the plaster.

2 Materials and Methods

The historic mortar was original material collected from the attics or the masonry of medieval churches and church ruins from different areas in Sweden. All of them are lime rich traditional lime mortars.

2.1 Methods for material analyses

To analyze mortar, new as well as old, there are several useful techniques such as Scanning Electron Microscopy, thin sections studied in light microscope and X-ray powder diffraction analyses.

Mortar samples were studied using Environmental Scanning Electron Microscopy (ESEM). The microscope used was a Quanta 200 SEM FEG from FEI. The samples were mounted on a carbon adhesive tape without further treatment.

SEM is a valuable technique for studying the structure and crystal sizes in lime [5, 6]. In addition, it gives information about the pore structure of the mortar and the size and appearance of the sand particles.

Optical microscopy studies of thin section mortar specimens were used to obtain information about the type of binder, the pore structure, the blending ratio, the minerals and grain sizes of the sand particles etc. [4, 7, 8].

Thin section specimens were prepared from historic mortar. An UV-fluorescent epoxy was used in a vacuum impregnation of the samples before they were polished down to a thickness of ca 3 µm and studied in an Olympus Bh-2 polarization microscope. The magnification of the pictures is shown for each picture.

The mineralogical composition of mortar was determined qualitatively by X-Ray Powder Diffraction (XRD). Only crystalline species can be detected by this method and the detection limit is 1-3 % (w/w). The instrument used was a Siemens D5000 powder diffractometer applying Cu characteristic radiation and a scintillation detector. The scanned 2-theta range was 10 to 70 degrees. The identification of components was carried out using the Joint Committee for Powder Diffraction Standards database.

3 Results and discussion

Examples of historical mortar investigated ocular are shown in figure 1-6. By performing an ocular investigation lots of information can be read. Tool marks, additives as well as bigger binder and aggregate particles are visible. Those surfaces have been found on the medieval churches on Gotland both outdoors in the joints and indoors on the attics.

Fig 1 Medieval joints in the tower of Linde church. Hard lime rich white mortar with very fine graded sand. Traces of tools used when applying the mortar.

Fig 2 Remaining plaster on a Romanesque choir still left on the attic of Norrlanda church. Very lime rich with fine graded sand. Traces from tools.

Fig 3 Two types of old mortar on the west façade of Othem church. They are both white and lime rich. One with fine graded sand and the other with larger rounded sand particles.

Fig 4 Remains of wood and coal in an extremely lime rich mortar on Norrlanda church. A very hard and compact mortar.

Fig 5 Joint on Fardhem church containing crushed red bricks. Pink secondary mortar based on lime.

Fig 6 The joints at the ruin from a citadel at Gothem. A bit yellowish lime mortar with large sand particles and remains of large coal particles.

The Scanning Electron Microscope gives information about the type of lime and the structure of the mortar. At a magnification of 100 x the air pore structure is visible as well as how the sand particles are embedded in the lime. At a magnification of about 2500 x the micro pore structure of the binder becomes visible. In even larger magnifications each crystal of the lime can be studied in detail. The shape and size of the crystals as well as how they are packed together give information for identifying the slaking and storing process of the lime [2]. For example, the earth slaking technique give large particles arranged in an airy structure while the wet slaking technique give smaller particles arranged in a dense and well packed structure.

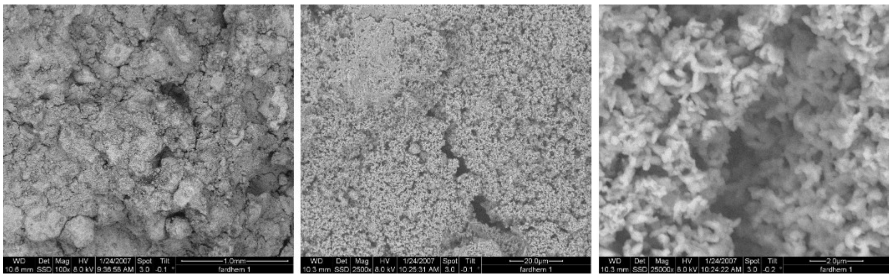

Fig 7 Medieval lime mortar from Fardhem church on Gotland, studied with SEM in three different scales (100x, 2500x and 25000x). It is a very lime rich mortar with more lime than sand, where the sand particles are imbedded in the lime. Several micro cracks and a few air pores are visible in the binder. The lime particles have the same sizes and are oriented in an airy structure.

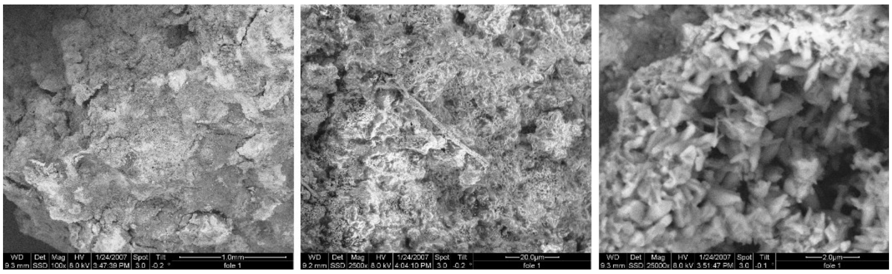

Fig 8 Medieval lime mortar from Fole church on Gotland, studied with SEM in three different scales (100x, 2500x and 25000x). Another extremely lime rich mortar with a few air pores visible. The lime particles exist in different sizes and shape, oriented in an airy structure.

Investigation of thin section specimens of mortar and plaster by optical microscopy was also found to be very informative in the studies of historic mortar. It can give information about the amount and type of binder and aggregate and of the mixing ratio between them. It also gives a lot of information about the pore structure and the surface working technique [3]. Additives or layers of lime wash can also be seen depending on how each sample was cut out. In the examples below several historic lime mortars from Sweden are shown. All regions are represented by lime rich mortars. A big unwhipped lime lump is visible in the second example from Fole. Additives such as wooden coal and sea shells become visible in the examples from Bara and Lundby. Layers of lime washes are made different at Garda compared to Älvros – fresco technique is followed by secco. The examples from Hassela and Sunne are made by hydraulic lime containing only small amount of aggregate.

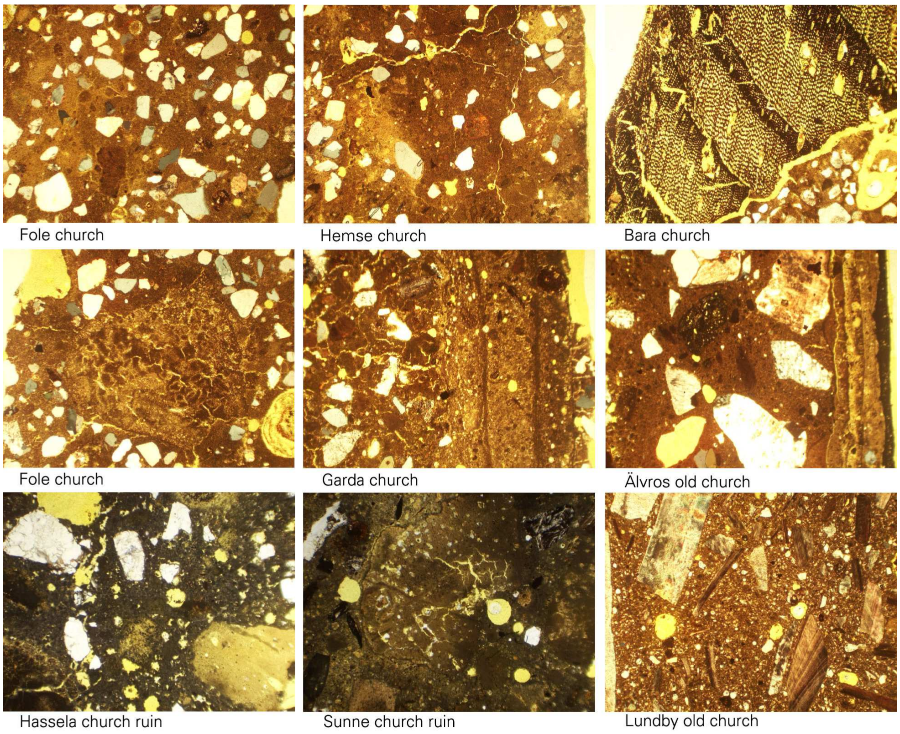

Fig 9 Examples of thin sections of medieval lime mortar from churches around Sweden. All of them are very lime rich. The first five examples come from the island of Gotland. The first two examples from Fole and Hemse church are typical medieval mortar based of lime and only a small amount of aggregates. They also contain only a small amount of air pores and micro cracks. The mortar from Bara church shows a piece of wooden coal. In the second example from Fole there is a lime lump of unwhipped lime. The examples from Garda (Gotland) and Älvros (Härjedalen) have several layers of lime wash on the surface made in different thickness due to the consistency of the lime wash. The mortar from Hassela and Sunne (from Hälsingland and Jämtland) contain hydraulic lime and only small amounts of aggregates. In the example from Lundby church (from Bohuslän) the aggregates are made of sea shells. The width of each sample is 4.5 mm.

Mineralogical analysis by X-ray powder diffractometer can be used as a complement to the optical methods mentioned above. Thus, the crystalline matter present can be detected and identified, see figure 10.

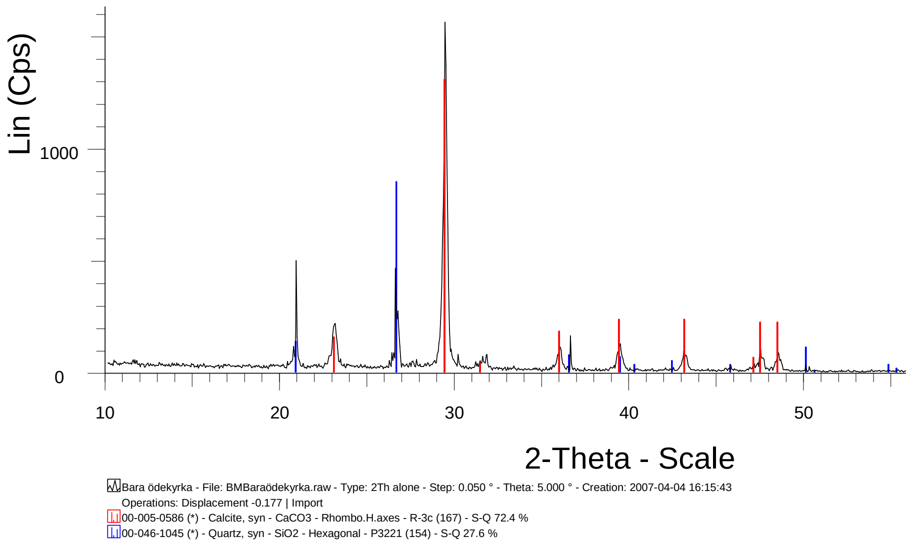

Fig 10 X-ray diffraction made on a medieval mortar sample from Bara church ruin on Gotland. The sample only contains $CaCO_3$ (kalcit) and SiO_2 (quartz); carbonated lime and quartz sand.

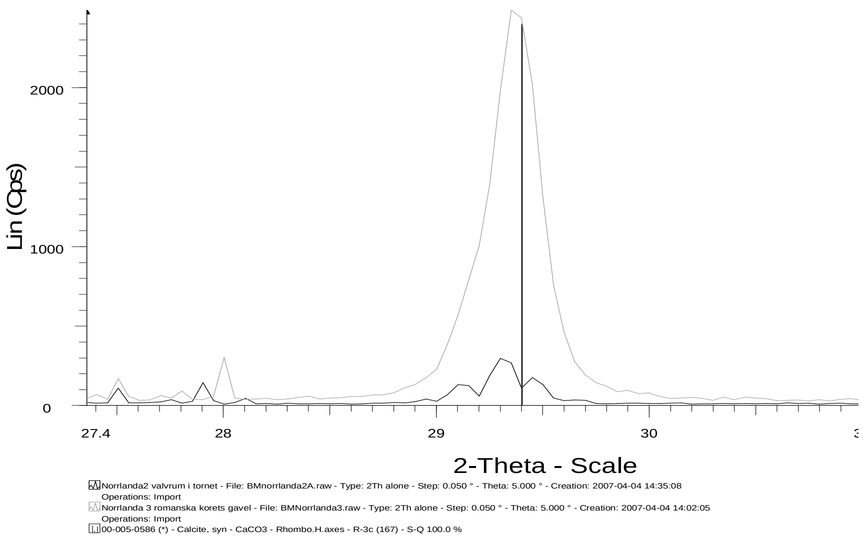

Fig 11 X-ray diffraction made on two medieval mortar samples from the attic of Norrlanda church on Gotland. The lower black line is from a joint inside the tower while the upper gray line is from a render surface once being an outdoor render on the choir but since the last building phase (around year 1300) it has been indoors on the attic. Because of the low intensity of the sample from the tower, the conclusion can be made that it has transformed and re-crystallized to a less crystalline form.

In some cases it is also possible to follow changes in the samples over time, as in the example in figure 11. In this case part of the rendered wall became an indoor wall in the attic during a reconstruction of the church. The plaster on this wall has been exposed to the indoor climate probably alternating between dry and humid and the lime has thus re-crystallized into a less well defined form (lower black curve) than it had on the other wall (upper grey curve).

4 Conclusions

The variation of historic lime mortars are as widely spread as there are sources of aggregates and sources of lime stone suitable to be burned. In a country with great geological variations the specific combinations and variations for each region need to be known. To be able to follow the international charters [9] saying that our architectural heritage should be restored with traditional materials compatible to the original material – we need detailed information about the original material. This paper has shown that one mortar defined as lime mortar is not likely to have the exact same composition and properties as another historic lime mortar. By combining ocular studies with analyses of thin section specimens, SEM and XRD the variations can be known and a proper restoration mortar can be designed to match the historic mortar in all possible ways.

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