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Experiences with Lime-Based Materials used in the Maintenance of Mediaeval Churches

Travelling in Denmark one gets the impression that the about 2000 mediaeval churches are very well kept. And generally speaking, this is a fact, thanks to a system where the local parishes take their responsibilities seriously. A democratically elected parish council is responsible for the maintenance of the church building and its contents. All repair work, however, or any change of the building has to be approved by the diocesan authorities. The diocese seeks advice from the Ministry of Ecclesiastical Affairs – among whose consultants the National Museum is included. The consultants can only recommend, but fortunately there is a tradition for good cooperation between the dioceses/parish councils and consultants. So, most often, the advice from the National Museum is followed.

Organization

The responsibility for the maintenance of the churches is, as mentioned above, undertaken by the parish council. Once a year it is obliged to inspect the building and its contents and report any defects. Every third year the inspection is carried out with the deanery committee and a building expert.

The financing of restoration projects and research connected with the work, whether it is the building, wallpaintings or furniture, is paid for by the church. The economy is based on a tax paid by all members of the established church and, if more money is needed – which is the fact in most cases – the diocese is able to grant a loan on easy terms.

In theory, guidelines for the preservation of the churches (older than 100 years) are well defined, but this does not prevent occasional mistakes from happening. The application of inappropriate materials or the inappropriate use of materials has occurred, and interventions with serious antiquarian losses have not been completely avoided. The regulations point out that general maintenance can be executed without consulting the authorities. However, the concept of 'general maintenance' has not been defined precisely, and as a result, the interpretation of this term varies among parish councils or masons. Nonetheless, major projects have always been executed under the leadership of an architect, who, in most cases, has great experience in restoration of churches. Together with the parish council the architect works out a project which must be presented to different authorities. The National Museum represents the antiquarian authority and collects and stores all archive materials. The appointed curator notifies the conservator when a professional evaluation is needed, i.e. consultation with the 'Limewash Service' which belongs to the Conservation Department of the National Museum.

Fig. 1. Ølsted Church (Jutland). Romanesque apsis, chancel and nave built of calcareous tufa. Tower and porch are late medieval and made of bricks. Limewashed.

Geological background and tradition for lime use

For centuries lime has been the basic product in the building of Danish mediaeval churches until the introduction of cement in the last century and synthetic materials in this century.

The subsoil in Denmark consists of lime of a pure quality created in the Cretaceous Period. Most important is coral and bryozoan lime. Additionally, travertine, calcareous tufa is found. The latter has been used in the construction of churches in certain areas, for example near Roskilde (Zealand) and Vejle (Jutland). During the Middle Ages lime was quarried in many places but in recent time it takes place mainly in Fakse, south of Copenhagen. This quarry delivers a coral lime.

As mortar material apart from pure calcium hydroxide, lime with hydraulic properties has also been in use. However, the fact that hydraulic lime from naturally-formed stone is only known from one location (Klintebjerg) might indicate that hydraulic properties analysed in some cases are really caused by impurities or by added hydraulic components.

The use of lime was based on a long tradition until the introduction of new materials. Over time, the increasing use of cement-based and synthetic products replaced the dominance of lime-based products. This resulted in a period of about 100 years during which the traditional knowledge was almost lost, and only a few masons had experience dealing with pure lime products, especially mortars and renders. Apart from the introduction of new products, the poor quality of lime was the reason why it was abandoned as a suitable material.

Lime has always been acknowledged in Denmark as the right material for restoration purposes, whether for use in wallpaintings or in the mediaeval church structure, but in spite of this, some repairs of the structure were occasionally carried out with cement as well as hydraulic mortars. But never in restoration of wallpaintings!

A well-slaked calcium hydroxide is the optimal material for limewash, but for a long period during the 50's and 60's only inferior qualities were avaible (calcium hydrate in powder form, or double-stamped calcium hydroxide). In 1976, however, the ma-

Fig. 2. Lime putty, quartz sand and limewater delivered ready for limewashing the cathedral in Århus.

son Michael Kjøng Jørgensen initiated a production of slaked lime for restoration purposes. The raw material was Fakse coral limestone. Following this initiative, others also took up the idea and started productions of well-slaked and stored calcium hydroxide.

The 'Limewash Service'

The 'Limewash Service' was established about 20 years ago. Already at that time conservators had for many years given advice to masons, as the conservation of the wall paintings often took place at the same time as the repair or maintanance work on the structure of the building. During the resulting cooperation between local craftsmen and conservators the exchange of experiences with materials and their use was common. The knowledge accumulated over the years is now used by the 'Limewash Service' in goal-directed advising in the common interest of preserving the church building and its wallpaintings. This is always carried out, of course, in close collaboration with curators, architects and parish councils.

As mentioned above, the parish councils are under no obligation to avail themselves of the 'Limewash Service'. The name 'service' underlines in fact that the consultancy is not founded on legislation. However, as the National Museum considers the 'lime service' to be an important part of preventive conservation, we offer a free first visit in order to have the opportunity to share our viewpoints and proposals with the church council. Only by being present in the church with the involved parties can the conservator become aware of the situation and have the possibility to correctly appraise the problems *in situ* and decide whether additional counselling is necessary. If this is necessary, an estimate of the costs of further involvement by the conservator will be made, and these will be paid by the church.

As part of the introduction, the suggested treatment is often carried out by the mason in cooperation with the conservator on a smaller surface, for example on one web of a vault. This way, the procedure can be clearly explained, and the mason has a good basis for estimating the consumption of time and costs in the final project.

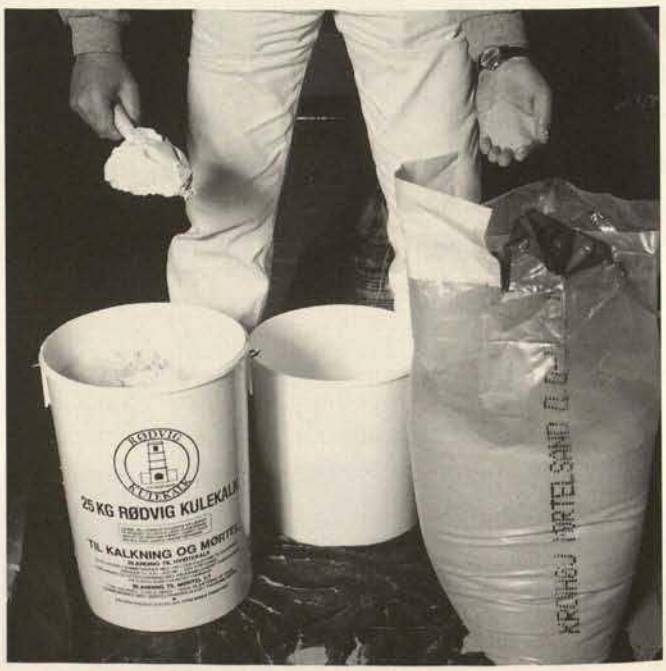
Procedure in interiors

The conservator/curator considers it to be important to save as many plaster and limewash layers as possible. If the condition of the surface is good it is usually appropriate to wash down, impregnate with limewater and limewash until a satisfactory appearence is obtained. However, the situation often demands a more thorough treatment, including the repair of cracks and removal of loose limewash and plaster layers. If you leave the decision to what extent layers have to be removed to a mason, much too much will often be done. Hollow areas are considered weak and will be knocked down and layers of limewash will be removed with rough tools.

In such cases valuable information is often lost, whether it is traces of wallpaintings or other layers which might be an important part of the history of the monument. That is the reason why it is of great importance for the conservator to go through the monument with the mason and instruct him on the procedures that will preserve as much as possible. Only having clarified the problems can the treatment take place.

We usually recommend standard mixtures (of which two are most frequently in use) for repair work and plastering: A rough mortar with aggregates up to 5 mm and a finer one with aggregates upp to 2,2 mm. Both are a mixture of slaked lime (lime putty) and washed and dried quartz sand. The use of slaked mortars (calcium oxide and aggregates slaked together) is still limited but hopefully more experiments with those mortars will take place in the future. Despite equal proportions between calcium

Fig. 3. Lime putty and quartz sand for producing a sandy limewash.



* The conservation of wallpaintings is directed and executed by the Wallpainting Section belonging to the National Museum's department of Conservation.

Fig. 4. A conservator informs and instructs the architect and mason. "The Limewash-Service" has an important role in promoting the position of the National Museum.

oxide and aggregates, the properties of the two types of mortars seem to be different. No scientific analyses have been carried out so far but empirical tests have shown that slaked mortars have better setting properties and less shrinkage than the mixed ones. Furthermore, masons have mentioned that the slaked mortar is a better product for construction works.

Hydraulic mortars are used in interiors in cases where static problems demand extra strength and for repairs in humid places, as, for example, in the foundations. Architects also often choose hydraulic mortars in the construction of floors.

The limewash is often prepared with addition of fine quartz sand to the lime putty. The method is especially convenient in cases where the preservation of old, and to some extent weak, layers is important. There are still quite a number of mediaeval wallpaintings covered by limewash layers in many churches, and attempts are made to avoid uncovering the paintings unless a technical reason demands it. Therefore, we try to work even on weak surfaces, and experience has shown that this is often possible by using a sandy limewash. The layer must be rather thick – resembling a slurry applied with brush. If a normal limewash is applied on a weak surface it often flakes off. Additionally, the sandy limewash creates a good base for further whitewashing with lime without sand. The absorption is good and uniform and the covering power is excellent.

The quartz sand added to the lime putty is of two different types: A rough one with a grain size from 0,2 mm up to 0,5 mm and a finer one from 0,0 to 0,3 mm. Often the use of the finest sand is sufficient, but in some cases it is necessary to apply the rough one as a first layer followed by the fine. Recently we have started experiments using a powder quartz size 200 µm, but with equal proportions to the above mentioned mixtures: 1 part lime putty to 4 parts aggregates. Water is added until a suitable consistency is achieved. It is important when working with sandy limewash that each treatment is completely dry before further applications. If not, there is a big risk of discoloration.

Sandy limewash, however, also has some disadvantages. It has quickly become a popular treatment used also by masons without experience, who use it without consulting the 'Limewash service'. As a result, the material is often applied in a too thin mixture or the aggregates used are too rough. A thin application does not differ from a pure limewash. Furthermore, the final aesthetic appearance is dependant on consistency, aggregates and application.

By using a sandy limewash we have succeeded in many cases in preserving limewash layers/decorations which otherwise were doomed to be lost. In addition, as economic restrictions do not permit the execution of requisite research each time an interior restoration is carried out, this treatment allows for an extension for another 20–30 years or more of the possibility of saving original material for future treatments by professionals who hopefully will develop methods of research, taking particularily difficult situations into account.

Fig. 5. Vallekilde Church (Zealand). The tower after cleaning in 1991. The lower part is made of granite boulders and the rest partly of hard-burnt bricks. In those areas, a cement slurry was preserved.

Fig. 6. Vallekilde Church (Zealand). After treatment in 1992 with a rendering made of slaked lime and aggregates up to 2,2 mm (1:2,5 volume). The church was limewashed the following year.

Fig. 8. Kirkerup Church (Zealand). The top side of a 14th century vault, with bricks showing deterioration caused by salts (mostly natrium chlorides).

Fig. 9. Kirkerup Church. Plaster protection layer applied (slaked lime and aggregates).

Fig. 7. Vallekilde Church (Zealand) 1996. The rendering has fallen off in the areas with cement and hard-burnt bricks. Repairs have later been executed with hyraulic mortar, which seems to hold.

Procedure on exteriors

The administrative procedure pertaining to the treatment of the facades of mediaeval churches follows that of works in the interior. We are, however, less involved in exterior treatments as those often consist solely of limewashing using slaked lime. If more radical interventions are planned the project passes the official way described above, and the curator decides whether it is relevant or not that a conservator pays a visit.

Mediaeval churches in Denmark are constructed from different materials. Most frequently this is granite, bricks or calcereous tufa. Today, many churches have plastered and limewashed surfaces, especially on the islands, and the limewash sometimes is pigmented with red or yellow ochre. Usually the tradition of coloured limewash is limited to certain regions.

The use of pure lime mortars is occasionally combined with hydraulic mixtures when treating exteriors. This depends very much on the state of the substrate, and futhermore, exposure to the rough weather in this country must be taken into consideration. At times, exterior repairs have been done with inappropriate materials, such as modern bricks, cement mortars and renderings etc. Very often these materials must be left partly intact, and therefore work is carried out on substrates which are not ideal for lime mortars.

The predominant wind in Denmark is from west or southwest, which means that the western and southern facades, especially of the towers, are highly subject to deterioration. Experience shows that a lime mortar/rendering is not sufficient on such areas, unless hydraulic lime is added. On the other hand, experience also shows that in areas where original building materials (e.g. mediaeval bricks, granite boulders) are preserved as base for the treatment, pure lime mortars work satisfactorily.

The conservator offers advice, but the final responsibility lies in the hands of the architect/parish council. That means that, in some cases, the decisions go against the recommendation of the conservator. This is a result of the fact that lime mortars alone have not yet fullfilled the demands pertaining to durability when compared to hydraulic mortars.

Protection of the top side of vaults

In recent years much attention has been paid to the condition of the top side of the brick vaults. Most salt problems in wallpaintings are related to the salt contents of the underlying bricks. The deterioration of the brick is often advanced before the problem is visible on the painting beneath. Based on these observations, preventive treatments are now carried out by applying a layer of plaster to the top side of the vault. In fact, this is a repetition of the original treatment, which in most cases was carried out upon finishing the construction of the vault. However, nobody had been aware of the importance of this layer over the following centuries, and when it deteriorated it was not replaced with a new layer. The function of the plaster layer is to absorb and release the humidity and prevent soluble salts from entering the bricks. The plaster is a sacrificial layer where the distintegrating actions of salt crystallizations will take place, instead of in the brick.

The application of the plaster must be done at a time of the year when there is no heating on in the church room (e.g. late spring). The top side of the vaults must be thoroughly dry-cleaned. A slight humidification by brushing water over the surface is sufficient, followed by application of a plaster slurry. This layer functions as humidification for the following plaster layer. The material used is 1 part slaked lime lime to 3 parts aggregates (up to 5 mm). The surface of the plaster is cut with a trowel in order to enlarge the surface.

In deference to curator's wishes to study the brick constructions, the application of plaster in most cases is limited to the areas which are known by experience to be most exposed. Areas where the risk of water penetration is serious, e.g. in the leaking joints between the nave and the tower, the nave and other added buildings, such as the porch.

Conclusions

Enjoying the sight of well-kept mediaeval churches one must be aware that this fact might also be the reason for a certain loss of historical information. This information has sometimes been registered, but not always. This might be a too high price to pay for the achievement of a room without cracks, white surfaces and newly-painted furniture. The threshold of what the parish council consent to as the acceptable level in terms of maintenance is becoming lower concurrent with the growth of economic possibilities. As a consequence, much attention therefore

Fig. 10. Århus Dome. Masons limewashing undecorated areas under guidance of a conservator.

must be paid to advising those responsible for the buildings to bring about an acceptance of a lower degree of maintenance, limiting treatments that exclusively pertain to the aesthetic presentation. When it comes to the materials used for repairs, the request is not how long they last, but always how long can we preserve the original materials these repairs are protecting. Lime-based materials have seemed so far to be suitable for that purpose, but our knowledge is still limited. That is why it is important for research in laboratories, as well as practice *in situ* to proceed.

Materials and proportions for mixtures used on church masonry.

Lime. Lime putty made from lime lumps (Fakse quarry) slaked with water without additives and matured for a minimum of 3 years.

Aggregates. Angular sand or grit, well-washed and oven-dried, free from silt, salt and organic matter.

Mortars. Only pure lime mortars are used for internal work on walls and vaults. For external work pure lime mortars are also used, though it can be necessary to add hydraulic lime when working on certain exposed areas, such as plinths, battlements, cornices and for reworking roof tiles and ridges, pointing and flooring.

Proportions for mixtures (standards). Rough mortar: 1 part lime putty; 3–3,5 parts quartz sand 0–5 mm. – Fine mortar (plaster): 1 part lime putty; 2,5–3 parts quartz sand 0–2,2 or 0–1,2 mm.

Limewashing. If the existing limewash does not provide a suitable support for further limewashing the following method is used:

A. After cleaning the surface with water a preparatory priming with lime water is sprayed or brushed on.

B. First layer of sandy limewash: 4 parts lime putty; 0,5 part quartz sand 0–0,3 mm; 0,5 part quartz sand 0,2–0,5 mm. – The mixture is thinned with water to a suitable brushing consistency depending on the condition of the underlayers' sucking capacity. The consistency must be quite thick and the material must be applied evenly. It should be left to harden 4–5 days (it has to appear white).

C. Second layer of sandy limewash: 4 parts lime putty; 1 part quartz sand 0–0,3 mm. – Applied as B. In many cases this mixture is sufficient without a first layer B.

D. Final treatment: Two or three coats ordinary limewash (lime putty thinned with water/limewater) until full covering is achieved and the sandy surface is filled.

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Fig. 11. Grinderslev Church (Jutland) Romanesque ashlars pointed with a lime mortar without hydraulic content.