Historic Materials and Their Diagnostic

State of the Art for Masonry Monuments in Norway

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1. Introduction

In Norway the Directorate for Cultural Heritage is the governmental body dealing with ancient monuments. More than 3900 Norwegian objects are scheduled as ancient monuments and thus protected by law. Included in the indicated number are churches, fortresses, lighthouses, different types of buildings and ruins. Among the listed objects are buildings of natural stone masonry, clay brick masonry and wood. In this state of the art-report only the masonry structures are dealt with and the renaissance of lime as mortar binder is especially focused.

The exact number of masonry monuments listed is clearly specified. It can however be mentioned that we have 152 stone churches, 70 stone ruins and 250 secular houses built before 1650.

In the period 1945-85 air lime very infrequently could be seen at Norwegian job sites. In the 1980ies, however, it was clearly understood that lime mortars was a "must" for a compatible restoration of ancient monuments and also of interest for other areas of application.

In this report the Norwegian climate as a deterioration factor is touched, results from tests of old and restoration mortars are presented and the state of the art regarding mortars for repair of historic masonry is discussed. Finally a brief overview of related projects in progress is given.

2. The Norwegian climate

The winter-time is relatively cold in the whole country compared with most of the European countries. The temperature can, however, vary a lot from coast to inland and also from south to north. Frost action and driving rain represent the main challenges for masonry structures. Air pollution is rarely an important factor when failures caused by lack of durability occur.

The amount of driving rain (water hitting a vertical wall) can be up to 1500 mm pr. year in western parts of the country (8400 – 500 mm in the Oslo region).

The number of days with both precipitation and freezing/thawing conditions is another parameter of special interest regarding deterioration of masonry materials. In Figure 2.1 this number is presented for a meteorological station outside Oslo (At the new international airport). In northern parts of the country the corresponding average number of days can be as high as 80 – 90. Hence only materials with good resistance to freeze/thaw action will survive in the Norwegian climate.

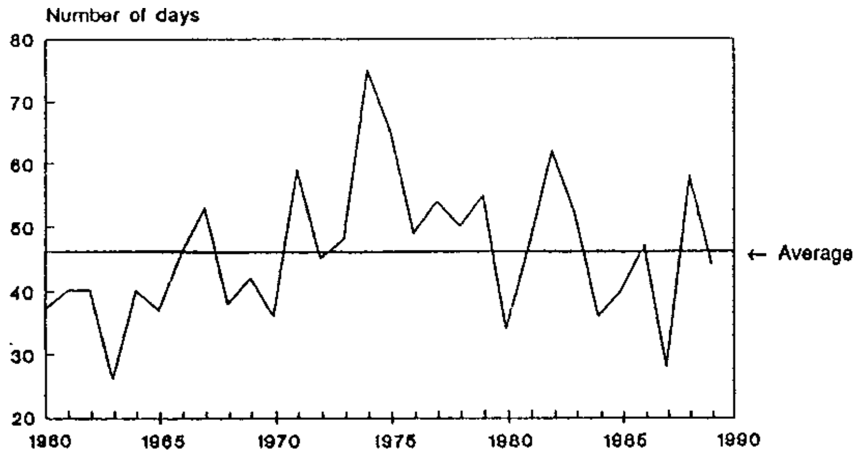

Figure 2.1

3. Ancient mortars – Constituents and properties

In the first decades after the World War II lime (L) as a mortar binder was used only for preserving and restoration of protected monuments. The experiences with the durability of L-mortars from this period was not good, the freeze/thaw-resistance was looked upon as not acceptable. We have, however, several medieval buildings with mortars of L-mortars with excellent durability properties. The question raised in the late 1980ies was therefore: How to produce L-mortars with the ingredients available to-day and the same quality as found for mortars produced 500 – 800 years ago?

Some information about burning and slacking lime, mixing procedures for mortars etc. was of course well known, but the knowledge in general was far from satisfying.

In order to gain a better knowledge about the properties of ancient mortars with good frost- and moisture resistance, mortar samples from historical buildings were gathered and examined.

The following types of laboratory investigations were carried out:

- proportional analysis (mortar compositions)
- density measurements
- water absorption measurements
- frost resistance tests
- compressive strength investigations
- microscopic investigations.

The mortar composition described as mass of binder in % of the total mortar mass was determined by two different methods (calculations based on analysis of the amount of soluble lime, CaO and of the ignition loss). Results for 13 test mortars are presented in Figure 3.1.

For some mortars the difference in parallel results for the two test methods are considerable. The divergences may be explained by inhomogenous mortar samples. The assumption that the CaO content in the binder was ca. 70 % by mass used in the calculation could also cause a divergency in the two results. The results, however, show that in old mortars the quantity of binder in comparison with that of aggregate is fairly large. This corresponds very well with parallel studies in the other Scandinavian countries.

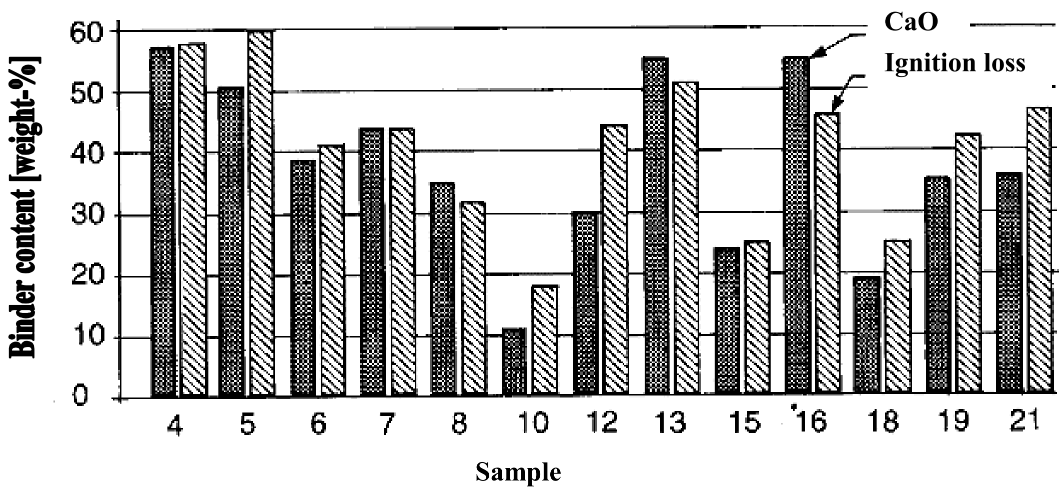

Figure 3.1 The content of binder in hardened mortar calculated from the amount of soluble lime (CaO) and of ignition loss

Studies of the mortar aggregate showed a big variation in the grain size distribution. The fact that the mortar aggregate in general had to be taken from sources in the neighbourhood of the site makes the variation understandable. With high binder content the grain size distribution of aggregate also will be of less importance.

The compressive strength for "high quality" historical mortars was normally determined to 3 – 5 N/mm² but masonry mortars with compressive strength up to 20 N/mm² were found (6 - 700 years old). The water absorption due to capillary action for the same "good" mortars was measured to 12 – 15 % by mass. Laboratory analysis did not indicate that organic additives in insignificant amounts were used in the mortars tested.

From thin section analyses it can be mentioned that the amount of air pores varied from 4 to 12 %. With low air contents regular pores with diameter less than 350 µm were dominating. For higher air contents (9 – 12 %) irregular pore shapes and air corridors were typical registrations.

4. Mortars for repair

4.1 Testing activities

The period with analyses of the ancient mortars was followed by research with the aim to develop repair mortars with high frost- and moisture resistance. Within the frame of the Eurocare project, "Eurolime", a relatively extensive test program was carried out. The main activities in the program were:

- Short time testing

  In the laboratory all the "basic" properties for the test mortars were determined. Weather resistance was, however, specially focused. Both freeze/thaw tests and accelerated ageing tests (cyclic short tests with driving rain, frost, sun radiation etc.) were carried out. Influence of pollution (NO_2, SO_2) was also included in the research program.

- Field applications

Exposure of test specimens at selected types of climate. For two years specimens of the test mortars used as renders on two different substrates (clay brick and natural stone) were exposed at three field stations in southern part of Norway. The purpose of the test was mainly to determine the weather resistance of the different test mortars in order to predict service life but also to evaluate results from the acceleration laboratory tests.

- Case studies

  Restoration of a couple of historical masonry buildings was included in the research project. The repair work consisted of rendering on clay brick and natural stone exterior walls, including lime wash coatings of repointing of natural stone masonry and of work of interior surfaces.

4.2 Test results - Examples

The composition of the tested mortars was 1:2 to 1:3 lime putty: aggregate (by volume). In the "good quality" ancient mortars relative coarse sand is often found. Grains up to 6 – 8 mm were often used for renders 20 – 30 mm in thickness and for masonry mortars. Preliminary laboratory tests with lime putties and the compositions in question did not indicate that a more coarse aggregate gives mortars with improved durability properties. The "to-days" recommended grain size distribution was therefore used in the test mortars. In principle, however, sand for repair mortars should be selected to match the sand grading in the various coats of the original render or of the masonry mortar.

Mortar additives like dolomite and crushed brick and air-entraining agent were included in the mortar-testing program.

It is generally accepted that the pore structure of a mortar is essential for the resistance to frost and salt deterioration as well as the water permeability. In our laboratory tests air content from 5 – 7 % was measured for fresh mortars without additives. Adding crushed brick or lime-stone filler did not change the air content significantly. With high air contents (> 15 %) by introducing air entraining agents the flexural mortar strength was strongly reduced (by 60 % with air content of 21 %). The effect of high air content on compressive strength of mortar was significantly less.

High air content had as expected a positive influence on the freeze/thaw and weather resistance. The effect of high air content on the mortar durability is, however, valid only for completely carbonated lime mortars. When working with hydrated lime mortars this, in fact, means that the carbonation process set the limit for finishing of the working season. For partly uncarbonated and wet mortars in freezing temperatures high air content will, according to the tests, not reduce the mortar deterioration.

In cold climate like we have in most parts of the Scandinavian countries, freezing temperatures is normal from the end of September to the beginning of May. With the slow carbonation process in mind, it is easy to understand that the summer period where hydrated lime mortars can be recommended for exterior jobs will be short. Focus on the carbonation rate will therefore be of great importance.

The carbonation depths were measured on mortar prisms cured in several storing chambers. Curing conditions of 20 °C and 65 % RH was found to give ultimate carbonation rate among the curing climates, but curing at 5 °C and 70 % RH gave nearly the same results (of importance for the Scandinavian climate).

Storing in dry climate (50 % RH) and spraying the specimens with water (1 minute every third day) had a positive effect on carbonation rate.

Both the exposure of test samples at field stations and the case studies documented that it was possible to produce air lime mortars with acceptable durability properties for several types of use in the Norwegian climate. There was, however, clarified that there are limitations for use of mortars with pure air-lime as binder.

One of the monuments restored as a part of the Euro-lime activities, was a fortress in the city of Trondheim. The facades of the fortress tower were restored in 1993/94 (Figure 4.1). A lime render was used. In the fall of 1993 carbonation depths of 8 mm after 2 months were measured. Frequent changes between sunny and rainy days were the typical weather situation in the period. The only failure on the rendered facades after 7 – 8 years is scaling of line-wash on areas with special strong climatic loads.

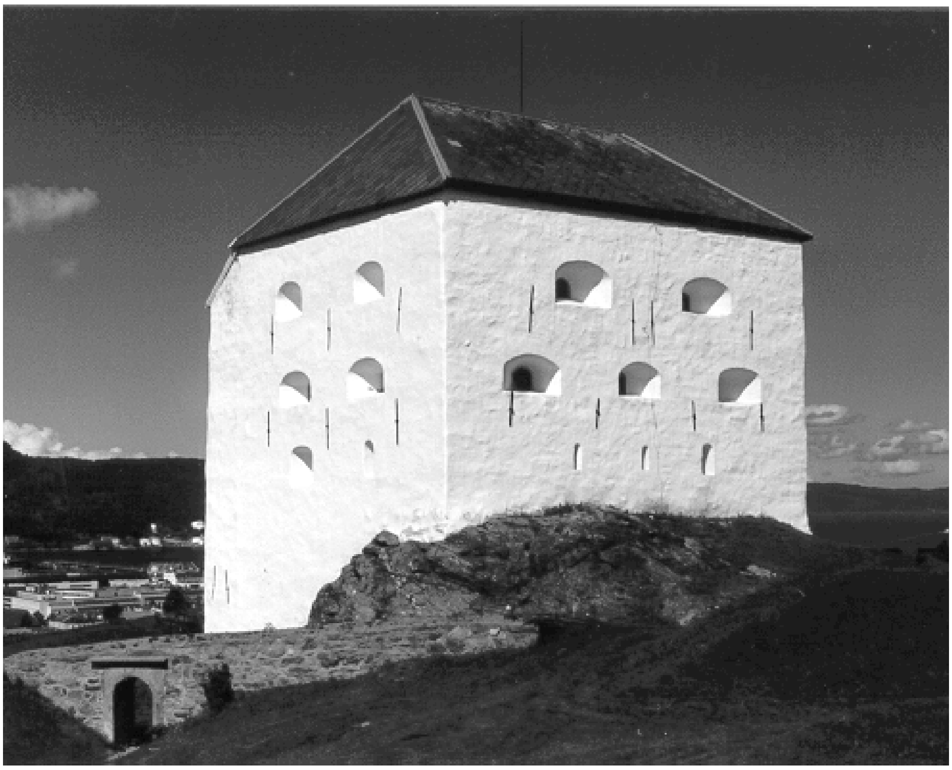

Figure 4.1

5. Status regarding mortars for repair

Based on to-days knowledge of historic mortars and their properties and the results from the tests of mortars for repair the choice of repair mortars will be:

- Airlime-based mortars can with few exceptions be used as renders on all building facades. For areas with special strong climatic impact (retaining walls, extension sills, ornaments etc.) mortars based on both airlime and a hydraulic binder, should be performed. The hydraulic binder can be hydraulic lime or cement. The mortar composition, sand graduation etc., should be designed individually for each monument.
- Pointing mortars represent more problems than rending mortars. The typical failures are frost damage or poor bond between mortar and stone. The results from the EU-project "Maintenance of pointing in historic buildings decay and replacement" will be of great interest. In Canada a similar work is in progress.

6. Ongoing projects

Since the masonry industry in Norway is relatively small, the research activity is limited. The activities related to historic masonry are often initiated from the Directorate of Cultural Heritage.

Projects in progress:

- handbook for ruins
- condition survey of lighthouses
- mortars with hydraulic lime – history and properties
- restoration of a memorial monument (pointing mortar and application is a central part of the project)
- life cycle assessment of lime mortars and cement mortars.

7. References:

[1] Tore Kvande and Alf M. Waldum: "Analyse av gamle kalkmørtler" (Analyses of old lime mortars). Report 239 Norwegian Building Research Instiute 1998

[2] M. Waldum; O. Anda: "Durability of lime-based mortars in a severe climate". Proceedings of RILEM Workshop Paisley Scotland May 1999