MORTAR LININGS IN DUCTILE IRON PIPES.

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ABSTRACT

To protect waterpipes made of ductile iron from corrosion, the pipes usually have a mortar lining on the inside. However, as most of the drinking water in Norway comes from surface water supplies with low pH, low alkalinity, and low hardness, the durability of the mortar linings and thereby its protection of the iron pipe against corrosion became a question. Some Norwegian municipalities therefore decided to investigate the condition of their existing water pipe lines.

Samples have been taken from pipelines at different places in the country. By use of Scanning Electron Microscopy (SEM) and Wave Dispersive Analysis of X-ray (WDAX) the linings have been examined with respect to degradations of the linings and leaching of elements (CaO) from the cement paste.

Scanning Electron Microscopy proved to be a well suited method for invstigation of the condition of mortar linings. The results showed that the service life of mortar linings can be as low as 20 years.

Key words: Water Pipes, Mortar Linings, Composition, Durability, Test Methods

1 INTRODUCTION

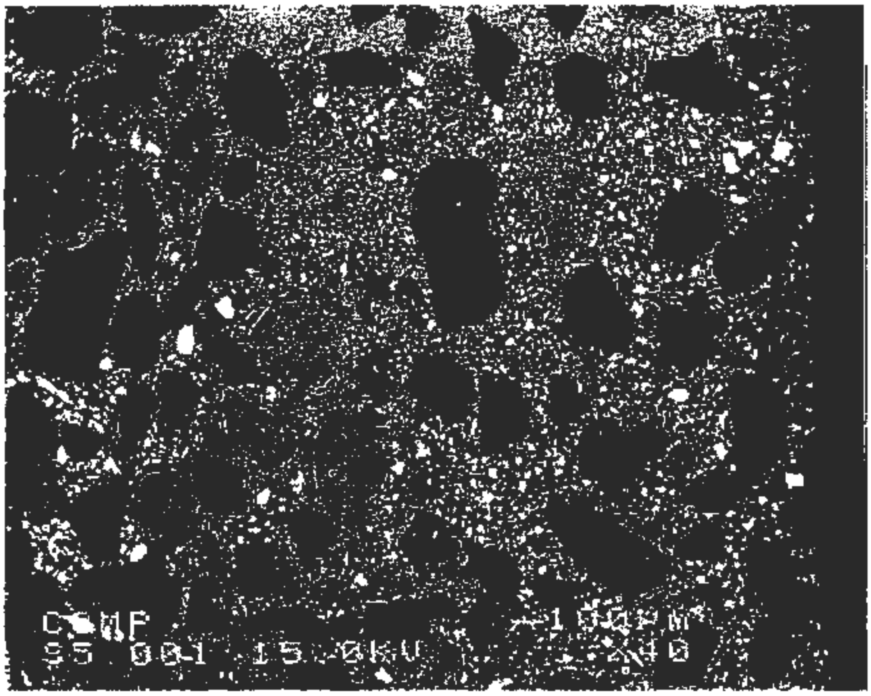
About 60 % of the pipes for drinking water supply in Norway consist of iron pipes. Before 1960 the pipes were not protected against corrosion. In addition to corrosion problems, these unprotected pipes very often caused a rather bad quality of the water. From 1960 and onwards pipes for drinking water supply usually are produced from ductile iron with some kind of internal lining material to protect the iron. Usually the internal linings are mortars of different composition with respect to type of cement and lining procedure. In most countries mortar linings have proved to protect the iron against corrosion, giving the pipes an extended service life and providing the customers with water of high quality /1/.

When the production of mortar lined iron pipes started in Europe, the know-how for both cement, mortar, and lining processes lay essentially with the manufacturers. Over a period of time greater European water works, especially in Germany, gained experience, and from 1970 onwards they began compiling their own mortar standards. These standards included requirements for max. w/c - ratio, cement content, compressive - and bending/tensile strength. The standards also established that no chemical admixtures should be added to the mortars /1/. National standards have been developed later on /2/.

As to the type of cement, it has now been decided that the manufacturers of mortar linings may use the cements which have been approved in their own countries. The cements mostly used in mortar linings, seem to be Ordinary Portland Cement, High Alumina Cement, Slag Cements, and Fly Ash Cements.

Codes of practice which cover methods for lining of "Factory Lined Cast Iron Pipes", have also been formulated. Today 2 methods of lining are in use: One is the centrifugal method, whereby a centrifugal head is pulled through the pipe and the lining is troweled. This method of lining gives the same cement : aggregate proportion throughout the whole thickness of the lining. The other method is to pass the pipe over a fixed centrifugal head and to rotate the pipe slightly in order to obtain a smooth surface. During this process the original mixing proportion changes giving a cement rich layer (cement : aggregate proportion about 3:1) near the water side, and a sand rich, porous layer (cement : aggregate proportion about 1:4) against the iron pipe side. Cross sections of linings produced according to these methods are shown on Figures 1 and 2.

A manual method of lining is also described. This method covers "in situ" lining of iron pipes. It was developed for cleaning and lining of old pipeline networks.



Figur 1 Cross section of lining produced by pulling a centrifugal head through the pipe, (steel to the left side).

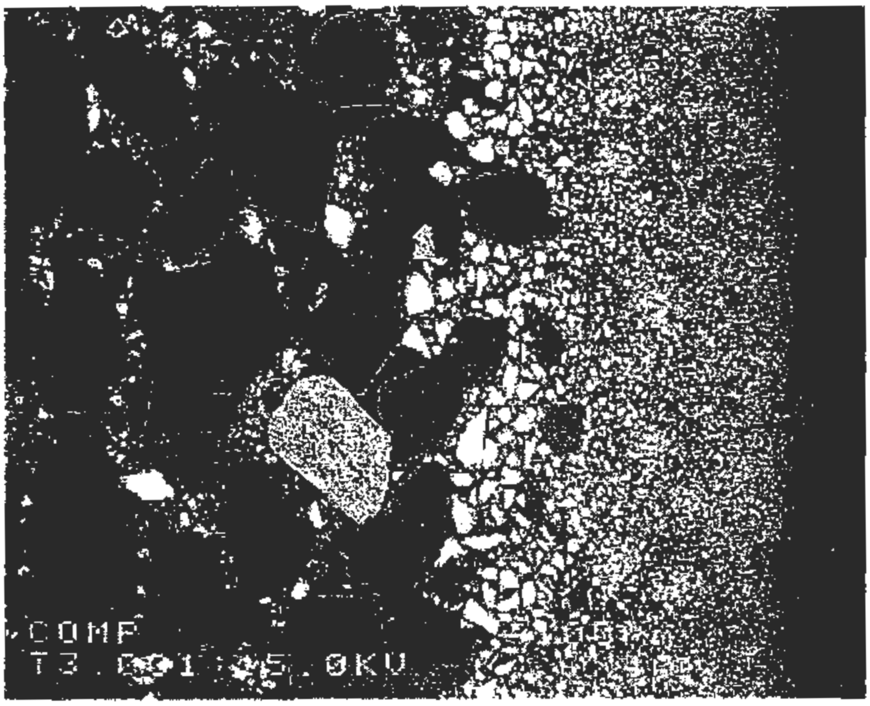


Figure 2 Cross section of lining produced by rotating the pipe over a fixed centrifugal head, (steel to the left side).

2 BACKGROUND AND AIMS

Chemical degradation of mortars is caused by penetration of fluids into the material. However, a small leaching of elements from mortar linings must be expected when the mortar is exposed to large
amounts of streaming water. The permeability of the mortar lining next to water is decisive for the mortars' resistance against penetration of fluids. To a large degree the permeability of a mortar depends on type of cement, w/c ratio, hardening conditions, design, workmanship and so on. Beside the mortar's quality, the degree of decomposition also depends on composition of the water with respect to pH, hardness, alkalinity, and content of salts.

The greater part of water supply in Norway comes from surface water. An examination of 349 surface water reservoirs and 35 ground water reservoirs showed following average compositions of the
waters /3/;

Surface water	pH: 6.7	Ca^{2+}: 2.6 mg/l	Alkalinity: 0.05 - 0.1 mmol/l
Ground water	pH: 7.3	Ca^{2+}: 8.7 mg/l	Alkalinity: 0.1 - 1.0 mmol/l

Comparing the average composition of surface water with that of ground water and recommended water [EEC-dir. 80/778 (see Table 1)], one may assume that the relatively short service life observed for some of the mortar lined pipes is due to properties of surface water. Even the recommended "EEC-water" does not guarantee a long service life of mortar linings /3/.

Compared with several other European countries, Norway has experienced a shorter service life of mortar linings than should have been expected. In order to investigate the condition of parts of the existing water pipe lines, a rather comprehensive research project was started. The aims of the project were to find suitable methods for examining mortar linings, and to do some examinations as to the state of mortar lined water pipes in attempt to make a basis for valuation of service life of mortar linings.

3 TEST PROCEDURES

Scanning Electron Microscope (SEM) in the Back Scattered Electron mode (BSE) and Energy Dispersive Analyses of X-rays (EDAX) have been used for the examination of the mortar linings.

Using the modus BSE in SEM for examination of mortar gives the possibility to distinguish between different phases and their distribution. It is important that the sample is properly plane polished. The backscatter process depends strongly on the average atom number of the sample, sample density and the energy of the primary electrons. Phases with high average atom number and / or samples with a dense structure will have bright colours on a SEM monitor. On the other hand, phases with low average atom number and samples with porous structures will have dark colours.

Together with the SEM-investigation, EDAX diagrams have been recorded. EDAX gives semi-quantative compositions of solid materials. The principle for the method is based upon the exitment of the electrons of each atom in the sample. When the electrons return to their stable energy level, the atoms in the sample will emit X-rays of a certain energy specific for each chemical element. The results will appear as peaks in a diagram with variation of energy as X-axis. The position (X) determines the elements, while the hight (Y) of the peaks gives the amount of the specific elements in the sample. By use of EDAX small areas of a sample are analysed with respect to chemical composition. EDAX is best suited for analyses of homogeneous materials. Because micro structure / chemical composition may change from one small area to another in inhomogenious materials like mortar and concrete, the results may differ. Therefore one has to evaluate the results very carefully when using EDAX for analyses of inhomogenious materials.

4 MATERIALS

The investigation included 15 mortar lined pipes obtained from municipalities at different parts of Norway. The pipes had been in use for 10 - 20 years. Chemical analyses of the drinking water, to which the mortars have been exposed, were also obtained, and are given in Table 1 together with the recommended European Standard for drinking water.

The mortar linings were loosened from the iron pipes. Specimens for investigation were taken right-angeled to the mortar linings, impregnated with epoxy, polished, and examined by use of Scanning Electron Microscope (SEM) in the Back Scattered Electron mode (BSE) and Energy Dispersive Analysis of X-rays (EDAX).

In order to investigate degradation of the linings, small areas of the polished specimens were analysed with respect to the main components of cement; SiO_2, CaO, Al_2O_3, Fe_2O_3, and MgO at certain distances from the water side towards the iron pipe.

Table 1 ANALYSIS OF DRINKING WATER

Water	pH	Alkalinity (mmol/l)	Calcium (Ca^{2+}), (ppm)
Water no. 1	8.0	0.91	29
Water no. 2	7.4	-	4
Water no. 3	7.3	0.56	12.3
Water no. 4	7.9	0.05	1.0
Water no. 5	6.3 - 7.4	0.1 - 0.35	< 5.0
Water no. 6	7.3	0.3	5.4
EEC - dir 80/778[1)]	> 6.5	≥ 1.0	15 - 25

[1)] Recommended European Standard for drinking water.

5 RESULTS

The examination of the mortar linings showed that all 15 pipes included in the project had been lined by rotating the pipes while passing them over a fixed centrifugal head. As mentioned earlier, this results in a segregation of the mortar, giving a cement rich layer with low w/c-ratio at the water side (see example in Figure 2)

The cements used in the mortars were either Ordinary Portland Cement or Slag Cement.

All 15 linings showed degradation in terms of leaching of elements from the cement pastes. This means that the mortars gradually lose their capacity to protect the iron pipe from corrosion.

Results from the SEM (BSE) examination of one of the specimens are shown on Figure 3. The photo shows a cross section through parts of a mortar lining. The water side of the lining is shown at the right hand side on the photo. Dark areas on the water side show leaching of material from the paste. The corresponding EDAX results are shown on Figure 4, and from this figure it can be seen that calcium (Ca^{2+}) has been leached from the cement paste to a depth of about 0.5 mm, which confirms the SEM-examination with respect to depth of leaching. This mortar lining had been exposed to water No 4 (See Table 1) for about 23 years, and turned out to be among the better ones in this investigation.

Some of the pipes investigated also showed a considerably reduced thickness of the mortar lining, which means contamination of drinking water and a dramatically reduced capacity to protect the iron pipe against corrosion. A few of the pipes investigated had only 2 mm thick lining left. Figure 5 show the remaining mortar lining of a 20 years old pipe exposed to water No 3 (see Table 1). The cement rich layer on the water side (at the bottom of the photo) had been totally removed. Light areas at the iron pipe side, at the top of the photo, turned out to consist of iron, confirmed by EDAX (point analyses) indicated that the iron pipe had partly corroded. Figure 6 shows the distribution of elements in the remaining paste.

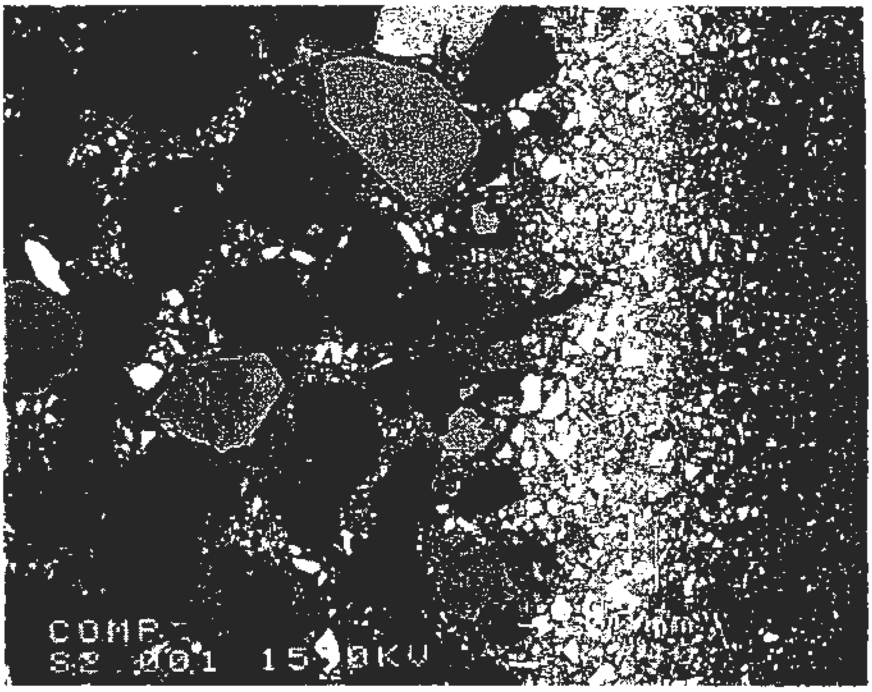


Figure 3 SEM (BSE) showing cross section of mortar lining. The water side is shown to the right on the photo. Dark areas at the water side mean a more porous i. e. leached cement paste. Magnf.: 40 X.

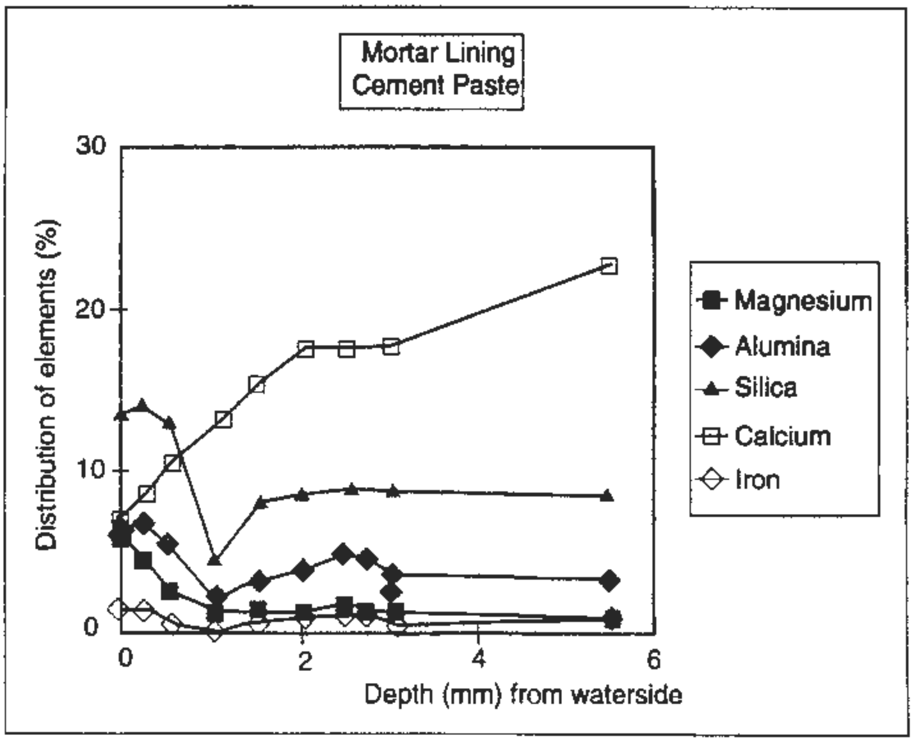


Figure 4 Distribution of elements (%) through the mortar lining.

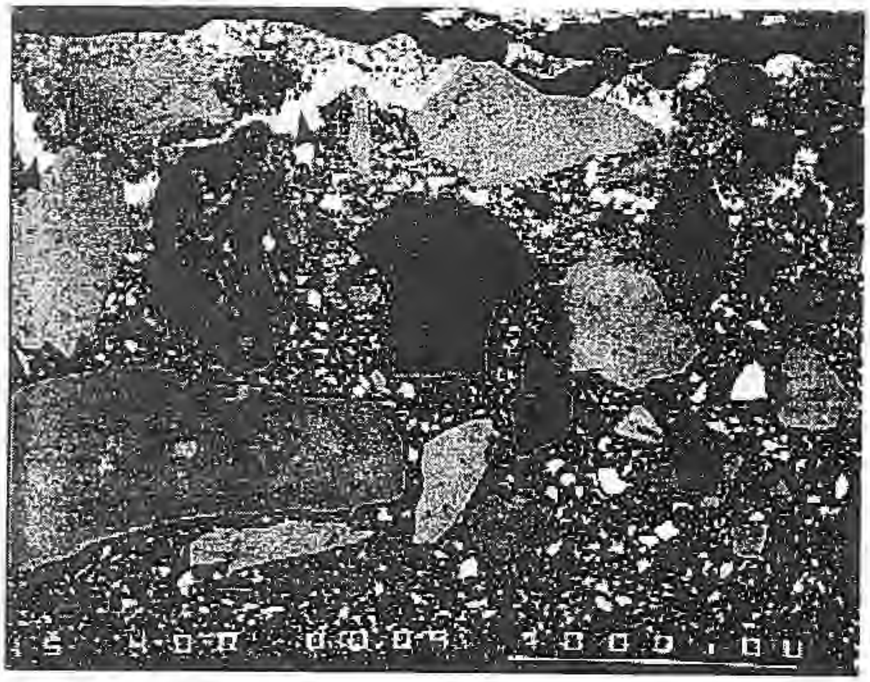


Figure 5 Leached 2 mm thick remaining mortar lining. Top side is next to iron. White areas marked with arrows indicate corrosion products which have penetrated into the mortar.

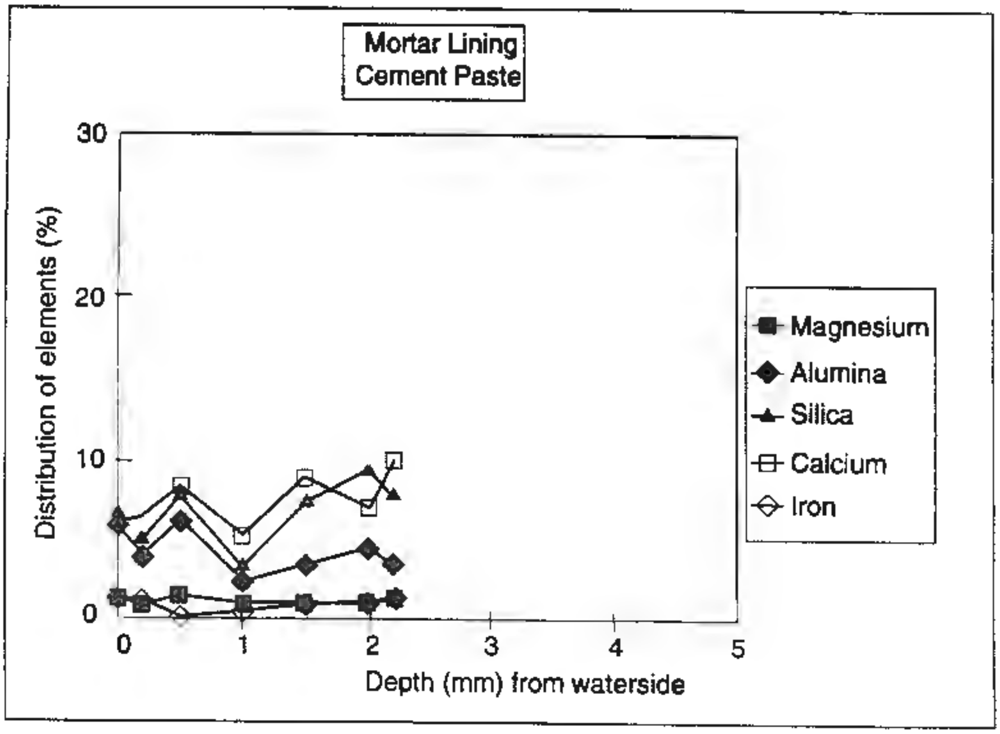


Figure 6 Distribution of elements (%) through the mortar lining.

6 COMMENTS

It is difficult to explain the great difference in disintegration between these two mortar linings. Both of them had been in use for about 20 years, and taking the water properties (see Table 1) into consideration, quite the contrary result should have been expected. However, circumstances which definitely will influence the durability of mortar linings are unknown. For instance,

* The distance from the water reservoir to the pipe. It is presumed that pH and content of calcium will increase and leaching capacity will decrease with increasing distance from the water reservoir.

* The properties of the water with respect to pH, calcium content, and alkalinity may have changed during the 20 years.

* Velocities of water flow to which the mortars have been exposed, may differ from one place to another.

* The original quality of the mortars with respect to mix design and composition.

7 CONCLUSIONS

The following conclusions may be drawn from this investigation;

* Scanning Electron Microscopy (SEM), in the Back Scattered Electron mode (BSE) combined by Energy Dispersive Analyses of X-rays (EDAX) are well suited methods for exmination of mortar lined iron pipes with respect to degradation / leaching of mortars.

These methods enable determination of which type of cement and which method of lining have been used by the manufactures.

* Parts of the water pipe lines may be in a rather bad condition.

* Service life of mortar linings can be as low as / or even less than 20 years.

8 REFERENCES

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/3/ Informations given by Research Engineer S. Østerhus, SINTEF NHL (Norwegian Hydrotechnical Laboratory), N-7034 Trondheim, Norway.