DURABILITY OF MORTAR LININGS IN DUCTILE IRON PIPES
Durability of mortar linings

I. S. MELAND
SINTEF Civil and Environmental Engineering, Cement and Concrete, Trondheim, Norway

Abstract

Mortar linings in ductile iron pipes for distribution of water have been investigated with respect to micro-structure, composition, durability and leach of chemical components. Scanning Electron Microscopy (SEM) and Wave Dispersive Analysis of X-ray (WDAX) have been used to study degradation of mortar linings which have been in service for 10 - 20 years. The same techniques have also been used to follow degradations and leaching of new mortar linings exposed to aggressive solutions in laboratory. Relatively good correlation has been found between the laboratory tests and the degradation of linings of pipes in service. Reliable methods for examination and testing of mortar linings in new pipes will definitely be a valuable implement for municipal water works to specify a wanted composition and quality of mortar linings.

Keywords: water pipes, mortar linings, type of cement, durability

1 Introduction

Among our building materials few of them affect our daily life as much as the water pipe line network. A steady delivery of water without any interruptions is of great importance to our quality of life. Also from an economic point of view it is important to have pipes of good quality in order to secure a long service life of the pipes without considerable expenses of maintenance. Traditionally, water mains consisted of ductile iron pipes without any protection against corrosion. From about 1970 - 80 internally mortar lined iron pipes came into use in Norway. Due to a high pH the mortar linings are supposed to protect the iron pipes against corrosion. However, dependent on physical and chemical properties of the mortar and / or the
quality of the water, any mortar lining is to be more or less attacked by the streaming water, and chemical compounds like calcium and alkalies are leached from the mortar linings. Unfortunately, the greater part of the water supply in our country comes from surface water. Drinking water has a low pH (average: 6.7), a low hardness (average: \( \text{Ca}^{2+} = 2.6 \text{ mg/l} \)), and a low alkalinity (average: 0.05 - 0.1 mmol/l). Most of the local water works are small and cannot afford to invest in water treatment equipment to increase pH and mineral content by adding lime or alkalies. Often the results are a comparatively short "service life" of mortar linings, which means great expenses on maintenance, repairs, and replacements of pipes, and bad water-quality due to leach of chemical components from the mortar.

2 Degradation mechanisms

The capacity of mortar and concrete to withstand chemical degradation can be related to three of the material's characteristica:
deeper into the mortar lining, the mortar may lose its capacity to protect the iron pipe against corrosion.

3 Mortar Linings

3.1 Methods of lining

Commonly two methods are used for lining of ductile iron pipes:

- Centrifugal method. The mortar mix is cast on the iron pipe when it is under a very high rotation velocity. This gives a cement mortar lining with a very cement rich layer towards the water with a porous and sand rich layer towards the iron pipe. A scanning microscope photo of the micro structure of this lining is shown in Figure 1.

![Fig. 1: Centrifugal lining method](image)

- Centrifugal projection head method. By this method the mortar mix is cast on a still-lying iron pipe through a spinning head. This gives a cement mortar lining with an equal distribution of cement paste, pores and sand throughout the whole thickness of the lining. A scanning microscope photo of the micro structure of this lining is shown in Figure 2.
3.2 Cements

If the mortar lining is exposed to soft water with low pH and low content of minerals, the type of cement used in the mortar may have decisive consequences for the durability of the lining. According to DIN 2614 following cements are allowed for mortar linings in pipes transporting drinking water, Ordinary Portland Cement (OPC), High Alumina Cement (HA cement), Blast Furnace Slag Cement (BFS cement), Fly Ash Cement (FA cement), and Sulphate Resistant Portland Cement (SR cement). One of the main components of a hardened OPC paste is calcium hydroxide \([\text{Ca(OH)}_2]\), and this is also the "weak" mineral of a cement paste and is easily leached from a cement mortar. Among the cements mentioned, OPC and SR cement have the larger contents of calcium hydroxide. Due to the raw materials HA cement is relatively low in \(\text{Ca(OH)}_2\). Also mortars based on BFS cement and FA cement have reduced content of \(\text{Ca(OH)}_2\) partly due to the lower content of OPC in these cements and partly because of the pozzolan reaction between calcium hydroxide and the mineral substitute in the cements.

4 Aims

The aim of the project was to find which of the mortar linings is the most suitable one for a specific water quality. This should be done by, firstly, to carry out a condition survey of mortar linings taken from existing pipes lines at different parts of the country. Secondly, to use accelerated laboratory test methods to investigate the durability of specimens taken from new linings, and to examine the conformity between the laboratory tests and the actual deterioration caused in performance by streaming water.
5 Experimental details

5.1 Materials
The experiments included mortar linings based on either Ordinary Portland Cement, High Alumina Cement, Blast Furnace Slag Cement, or Fly Ash Cement.

5.2 Test methods

5.2.1 Scanning electron microscope (SEM)
The mortar linings have been investigated by use of Scanning Electron Microscope (SEM). Using Back Scattered Electron modus (BSE) in Scanning Electron Microscope (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 back scatter 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, as iron (Fe), and / or samples with a dense structure will have bright colours on a BSE image. On the other hand, phases with low average atom number, as magnesium, and samples with porous structures will appear dark.

5.2.2 Wave dispersive analysis of X-rays (WDAX).
Together with a SEM-investigation Wave Dispersive Analysis of X-rays (WDAX) diagrams have been recorded. WDAX gives semiquantitative compositions of solids. The principle for the method is based upon the exitement 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 element, while the height (Y) of the peaks gives the amount of the specific elements in the sample. By use of WDAX small volumes ($\approx 1 \, \mu m^3$) of a sample are analysed with respect to chemical composition.

5.2.3 Accelerated Leaching Test
An accelerated leaching test has been performed by using a modification of the Dutch method NEN 7345. According to this method samples of concrete or mortar are exposed to deionized water or acid solution for 64 days. At certain intervals during this period samples are taken from the solutions and analysed with respect to calcium and aluminium.

5.3 Experiments

5.3.1 Mortar linings in used pipes
Specimens of mortar linings were impregnated with epoxy and plane polished. Deterioration of the mortars has been studied by use of scanning electron microscope (SEM) and wave dispersive analysis of x-rays (WDAX). In addition leaching of elements (CaO and Al$_2$O$_3$) from the matrix has been determined by analysing the
cement pastes at certain distances from the water side towards the side of the iron pipe.

5.3.2 Mortar linings in new pipes

For accelerated deterioration tests of mortar linings specimens of about 130 x 70 mm were cut from the pipes, isolated by epoxy, and exposed to acetic acid buffer solution (pH = 4.6) for 64 days. The solution was kept in movement throughout the testing period. A buffer solution was chosen for the experiments because the buffer solution gives a relatively permanent pH even when Ca(OH)₂ is leached from the mortar. This gives allowance to compare a buffer solution with streaming water. During the exposure period samples have been taken from the solutions and analysed with respect to contents of calcium (Ca²⁺) and aluminium (Al³⁺) by use of atomic absorption spectrophotometer. Durability of the mortar linings has been estimated by SEM / WDAX examinations of the specimens before and after exposure. In addition the thickness of the linings has been measured before and after exposure in the buffer solution.

6 Results and discussion

6.1 Mortar linings from pipes taken from networks

The investigation included 15 mortar lined iron pipes taken from pipelines at several water works throughout the country. The pipes had been in use for 10 - 20 years. SEM (BSE) and WDAX showed following results:

- The cements used in the mortars were Ordinary Portland, Blast Furnace Slag Cement or Fly Ash Cement.
- Both the centrifugal method and the centrifugal projection head method had been used in lining the pipes.

All the specimens showed degradation of the mortar lining in form of leached elements. This means that water delivered to the people (consumers) may not have the wanted quality due to a high pH caused by leaching of calcium and hydroxyl ions from the mortars. At the same time the leaching of calcium hydroxide also causes a gradually loss of capacity to protect the iron pipe against corrosion. A typical SEM photo of a mortar lining taken from a network is shown in Figure 3. Three distinct layers can be seen on the photo. That means a gradually leaching of the cement paste. The black area at the bottom of the photo, which shows the "water side" of the mortar, indicates a strongly leached paste, whilst the inner white area indicates that no leaching of elements has occurred.
A considerable reduction of the linings' thickness could be observed in some of the pipes, especially in those lined by the centrifugal projection head method. Linings from a couple of pipes which had been exposed for about 20 years to water quality: pH = 6.5, calcium (Ca$^{2+}$) = 1.5 mg / l, alkalinity = 0.04 mmol / l, were totally destroyed, and by SEM / WDAX iron rich layers could be observed in the remaining mortar lining. This result indicates that corrosion of the iron pipes has started.

Due to these results, which showed that mortar linings could be in a rather bad condition after 10 - 20 years in use, it was decided to do some laboratory tests on new mortar linings in order to evaluate which type of mortar i. e. cement and method of lining were the most durable one.

### 6.2 Mortar linings in new pipes

The investigation included mortar linings based on the following types of cement, FA cement, BFS cement, and HA cement. The mortar based on FA cement had been cast on to the iron pipe by the centrifugal projection head method. Whilst the centrifugal method had been used in lining the pipes with the BFS cement and HA cement mortars.
Measurements of the linings' thickness before and after exposure in acetic acid buffer solution showed:

- Non reduction in thickness of the mortar based on HA cement.
- A reduction of 0.5 - 1.0 mm of the mortar based on BFS cement.
- A reduction of about 3 mm of the mortar based on FA cement.

6.2.1 Accelerated leaching test

The total quantities of calcium and aluminium leached from the mortars during 64 days are given in Table 1. The results are calculated as oxides, and given in mg/cm² exposed mortar surface.

<table>
<thead>
<tr>
<th>Table 1: Leached CaO and Al₂O₃ (mg/cm²) from mortar linings after 64 days of exposure in acetic acid buffer solution.</th>
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<td><strong>Component</strong></td>
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<tr>
<td>CaO (mg/cm²)</td>
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<td>Al₂O₃ (mg/cm³)</td>
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The relatively large quantity of Al₂O₃ leached from the HA cement based mortar, is due to the raw material used in the production of this cement. When following the quantities of leached Ca and Al from the mortars at each testing time, the results indicated a very rapid leaching from the mortars based on FA cement and BFS cement, respectively. The leaching from the HA cement based mortar, however, went on through a longer period of time.

6.2.2 SEM / WDAX

SEM / WDAX examinations showed leached linings into a depth of 0.75 mm for the HA cement based mortar. Corresponding results were 1.5 mm and 2.0 mm respectively for the FA cement and the BFS cement based mortars. It should be noticed, however, the great reduction of thickness of the FA cement based lining during the test period. A WDAX diagram with respect to leached Ca and Al from the HA cement mortar is shown on Figure 4.
7 Conclusion

The results from the accelerated test indicated following:

- When exposed to concrete aggressive solution, mortars cast on to the iron pipe by the centrifugal projection head method seems to lose material to a larger degree than mortars cast on to the iron pipe by the centrifugal method. This has also been observed in examinations of used pipes taken from networks. This means that the dense cement layer obtained by the centrifugal method, has a very small permeability.
- Mortar based on High Alumina cement is more durable in concrete aggressive solutions with low pH compared to the other mortars included in the experiment. This means that a High Alumina cement based mortar lining will have a longer "service life" at low pH than linings based on Blast Furnace Slag cement or Fly Ash cement.
- The smallest total amounts of calcium and aluminium leached into the solution were measured from the Blast Furnace Slag cement.
- Rather unexpected high amounts of calcium and aluminium were leached from High Alumina cement mortar.
8 Recommendation

Based on the results from the accelerated test programme, ductile iron pipes lined by the centrifugal method with mortar based on Blast Furnace Slag cement, can be recommended for pipelines, which are going to be exposed to a moderate water quality.

For extreme water qualities, water with low pH, low content of calcium and low alkalinity, High-Alumina cement based mortar linings should be recommended.

9 References

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