Tools to monitor corrosion of cement-containing water mains

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Abstract Approximately 40,000 km of the drinking water network in The Netherlands consists of asbestos cement water pipes. The number of fractures in these pipes has increased greatly in recent years. This is due to corrosion of the asbestos cement (AC) which affects the condition of the pipe. Every time a fracture occurs, the question is raised of whether the pipe in question has to be replaced or repaired. A relatively simple destructive technique and non-destructive tests are used on a large scale to assess the condition of the AC pipes in use. Not only is corrosion detrimental to the pipes themselves, it also influences the water quality. Corrosion of the inner walls of cement-containing pipes involves the leaching of hydroxides. This causes pH changes resulting in scaling in water mains and domestic installations. Monitoring techniques have been developed to determine the effects of leaching on water quality.

The large-scale use of the relatively simple techniques at water companies increases insight into the condition of the drinking water network, the life expectancy of the pipes and the effects of corrosion on the water quality. Applying these techniques enables those involved to make decisions on pipe replacement and to provide solutions for reducing the effects of leaching.

Keywords Asbestos cement; cement mortar; condition assessment; monitoring techniques; water quality

Introduction

Approximately 35% of the pipes used for the drinking water network in The Netherlands consist of asbestos cement (AC). The number of fractures in AC pipes has increased greatly in recent years as a result of corrosion of the AC. Pipe fractures cause inconvenience for the consumer and contribute to higher repair costs for the water companies concerned. Furthermore, when such an incident arises, the water company is confronted with the question of whether the pipe should be replaced or repaired. More information on the condition of the pipe is needed to be able to answer this question.

Water quality problems may also arise due to corrosion of AC pipes. As a result of leaching of calcium hydroxide, the pH of the drinking water rises which, in turn, can lead to an increase in scaling in drinking water plants. Monitoring techniques have been developed, within the framework of research carried out for Dutch water companies, to determine the effects of leaching from AC pipes on both the water quality and the condition of the pipes themselves.

Mechanism

Asbestos cement, concrete and cement mortar consist largely of cement, which serves as a binding agent for asbestos fibre, gravel and sand respectively in these materials. Cement contains a very large number of compounds, the most important being tricalcium silicate (Ca₃SiO₅), dicalcium silicate (Ca₂SiO₄), tricalcium aluminate (Ca₃Al₂O₆) and calcium hydroxide Ca(OH)₂. These cement salts hydrate in contact with water and Ca(OH)₂ is formed. The latter dissolves on contact with water, releasing Ca²⁺ and OH⁻ (Troxell et al., 1968; Schock and Buelow, 1981).
As a result of the leaching of calcium hydroxide from the cement, the pH rises and the Ca\(^{2+}\) concentration in the water increases. When the pH and the calcium content rise, the calcium precipitation potential also increases. This can increase to the point that calcium precipitation even takes place during distribution. Calcium carbonate can then precipitate on the pipe walls, but also in the form of small particles in the water (microcrystals). A rise in pH is not always ascertained, but this does not necessarily mean that leaching is not taking place. The rise in pH due to leaching can be compensated for by a drop in pH resulting from calcium precipitation or microbiological processes in the network. Problems with calcium precipitation will arise particularly when the drinking water is heated, for example in hot water heaters. Leaching from asbestos cement can primarily be observed in cases where piping diameters are small (100 to 150 mm), residence times are long, and the drinking water has a low Saturation Index (SI) and a low buffer capacity (Slaats et al., 1993).

Leaching from AC pipes can also reduce pipe strength and eventually cause fractures and leakage. The leaching of calcium hydroxide from the pipe walls is the most important factor in the deterioration of the condition of AC pipes (Sterk et al., 1999).

**Monitoring methods**

**Condition assessment**

The degree of leaching from pipe walls is, therefore, deemed a measure of the condition of AC pipes. In The Netherlands, two methods have been developed for predicting the condition of AC pipes: the phenolphthalein test (which is a destructive test) and the Georadar test (which is a non-destructive test).

**The phenolphthalein test**

The extent of leaching from AC pipe walls can be determined using the phenolphthalein test (Leroy et al., 1996). To this end, a part of the pipe is removed such that a fresh fracture surface is formed. Phenolphthalein solution is applied to the fracture surface over the whole diameter of the pipe wall using a dropping bottle. If the pH of the material is higher than 8.3, the asbestos cement turns purple. If the pH is lower than 8.3, the asbestos cement remains colourless or grey. This indicates that calcium hydroxide has been leached out of the asbestos cement. The thicknesses of the leached part and the pipe wall are measured using a slide gauge at the spots where the maximum leaching has taken place. Subsequently the leaching percentage of the wall is calculated.

The data from research projects on the leaching of AC pipes in The Netherlands are collected at one central database at Kiwa. This database also contains data on the water and soil composition at the locations from which the AC pipes have been removed. From these data, relationships can be established between leaching and water quality parameters such as pH and SI and external influences such as the soil and ground water. The effects of changes in these parameters are determined by illustrating the averages of the values measured for one parameter as a function of a second parameter in graphs. The related number indicates the number of measurements.

On the basis of the data that are available thus far it can be concluded that there is a significant relationship between the SI of the drinking water and the leaching of the inside of AC pipes (Figure 1). The relationship between the leaching of the outside of AC pipes and the soil is less clear. No leaching of AC pipes occurs at soil pH values above 6 to 7. Leaching of AC pipes is more likely at pH values below 6 (Figure 2).
Georadar technique

The phenolphthalein test can only be carried out with parts of the piping that have been taken out of the network and is, therefore, destructive. In the event of pipe fractures, this does not form a problem. In the event that pipes are still complete, however, a non-destructive method for determining the condition of pipes is preferable if interruptions in water supplies are to be avoided. A non-destructive method is used to determine the leaching of AC pipes in The Netherlands. This is the so-called “Georadar technique”. This technique originated from the soil survey sector and has already been used for investigating sewerage piping in the Netherlands for some time. A study was recently carried out to determine whether the technique was suitable for AC water pipes. The advantage of the technique is that it is not necessary to interrupt the water supply although the pipes do have to be uncovered.

The principle of the investigation of materials using radar is based on the delay and reflection an electromagnetic wave undergoes in the walls of AC pipes. During radar
research, the differences between the time and signal strengths of an impulse which is emitted and the reflection signals are measured (Figure 3). These differences in time and signal strength are determined by differences in layer thicknesses and the characteristic electrical properties of the various layers from which the AC pipes are built up. The structure of the pipe wall being examined can be determined from the values measured. Use is made of a high frequency antenna with an intermediate frequency of 1 GHz. This antenna is moved forward manually over the measuring trenches. A radar recording is made for every 5 millimetres of the pipe covered. This density yields sufficient information.

In order to determine the suitability of the Georadar technique for use on water mains, the results of measurements obtained using the Georadar technique were compared with results from the phenolphthalein test on pipe segments from the same AC pipes. Table 1 gives the results of the measurements from the investigation of a 50-year-old AC pipe originating from the distribution area of the water company, Brabant Water. The table shows that the results obtained using the Georadar technique are comparable to those from the phenolphthalein test. The Georadar technique is thus a suitable, non-destructive method for determining the degree of internal leaching from AC pipes. Additional validation measurements are necessary to determine whether the Georadar technique is also suitable for determining the degree of external corrosion, amongst other aspects.

The accuracy of the phenolphthalein test and the Georadar technique is comparable. The information delivered by both tests is somewhat different. The phenolphthalein test gives the actual leaching of a ring of an AC pipe, while the Georadar test gives information on the stratification of the AC pipe wall. It is assumed that the stratification represents leached AC and non-leached AC. If more detailed information from the Georadar test is needed, it is recommended to verify the results of the Georadar test by carrying out the phenolphthalein test on some samples of the AC pipe.

Both the phenolphthalein test and the Georadar technique give information on the reduction of the effective wall thickness of the AC pipe. The condition is a combination of wall thickness and strength of the material itself. The results of the phenolphthalein test and also the Georadar test give restricted information on the residual strength, because the initial

![Figure 3](https://iwaponline.com/wst/article-pdf/49/2/33/420555/33.pdf)

**Figure 3** Sketch showing the principle of radar measurement

**Table 1** Comparison of the degree of leaching from a 50-year-old AC pipe measured with the phenolphthalein test and the Georadar technique

<table>
<thead>
<tr>
<th>Pipe segment</th>
<th>Outside diameter</th>
<th>Wall thickness</th>
<th>Leaching inside</th>
<th>Leaching outside</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenolphthalein test</td>
<td>1 130.5 mm</td>
<td>15.2–15.4 mm</td>
<td>max 1.5 mm</td>
<td>–</td>
</tr>
<tr>
<td>2 130.0 mm</td>
<td>14.5–14.8 mm</td>
<td>max 2 mm</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Georadar technique</td>
<td>Length of 1.5 m</td>
<td>15.1–15.5 mm</td>
<td>2 mm</td>
<td>–</td>
</tr>
</tbody>
</table>
strength of AC pipes appears to be very variable. The exact residual strength is difficult to establish because of very stringent health restrictions on working with asbestos cement.

Comparison in the field
In The Netherlands, the phenolphthalein test and Georadar technique are applied on a large scale for determining the condition of pipes and predicting the remaining life expectancy of pipes in real terms. An example of the use of these techniques is the determination of the condition of NUON Water’s AC pipes of Ø 800 mm. The pipes were presumably laid in 1957 or 1958 (Anzola et al., 2000). The water company, NUON Water, is responsible for supplying a town of approximately 140,000 residents with drinking water via an AC conveyor pipeline of Ø 800 mm. The extent of leaching from the pipes was determined in order to guarantee supplies. Using the phenolphthalein test, it was determined that approximately 4–6 mm had been leached from the whole internal cross section of the pipes. No external leaching was ascertained. The wall thickness varied from 41–44 mm. This corresponds with 9–15% leaching.

The radar measurement indicates that approximately 6.5–16.5% has been leached from the inside of the AC pipes (Table 2). On the basis of the measurements, in combination with strength calculations, the measured pipe segment is expected to continue to function without interruptions due to leaching for another 30 years, with the current water composition.

Effect on water composition
Changes in pH during distribution can be determined using monitoring systems. These monitoring systems continuously measure a number of water quality parameters, such as the pH, turbidity and conductance. The monitoring systems can be connected at various places in the network to the AC or cement-lined cast iron pipes. Comparisons of the pH values measured at various places give insight into the pH changes in the pipes.

The Kiwa monitoring system was developed for this purpose. The principle of the monitoring system is shown in Figure 4. The first monitor measures the incoming water quality, the other two (or more) record the changes in water quality during transport through the system. The effects of pH changes on the calcium precipitation potential can be determined using techniques to determine parameters such as the Calcium Carbonate Precipitation Potential, the Saturation Index and the Measured Calcium Carbonate Precipitation (TPCC₉₀, SI₉₀ and MCCP) (Brink, 1997).

Figure 5 shows the results of pH measurements at the pumping station and a number of places along a Ø 100 mm AC pipe in the water company, Vitens’ distribution area of PS

<table>
<thead>
<tr>
<th></th>
<th>Average wall thickness (mm)</th>
<th>Average structurally-sound part (mm)</th>
<th>Minimum structurally-sound part (mm)</th>
<th>Leached internal surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
<td>41.5</td>
<td>38.1</td>
<td>34.7</td>
<td>8.2–16.3%</td>
</tr>
<tr>
<td>Crosswise</td>
<td>40.5</td>
<td>37.9</td>
<td>35.6</td>
<td>6.4–12.1%</td>
</tr>
</tbody>
</table>

Figure 4 Kiwa monitoring system
During the measuring period the residence time was shortened on Friday by opening a fire hydrant. The effect of shortening the residence time on the pH was soon visible: the rise in pH decreased so that the calcium precipitation also decreased. This was shown by measuring the Measured Calcium Carbonate Precipitation before and after the adjustment of the residence time of the water in the pipes (Table 3).

Results from monitoring measurements may contribute to the optimisation of the treatment of drinking water. In general, problems caused by leaching from AC pipes can be limited by raising the SI and the buffer capacity. To prevent degradation of the drinking water quality targets for the composition of drinking water leaving the production location, an SI higher than −0.2 and TIC content higher then 2 mmol/l are required to control aggressiveness towards cement-containing materials. TIC stands for the total concentration of carbon dioxide, bicarbonate and carbonate (Van den Hoven and Eekeren, 1988).

**Conclusions**

Corrosion of AC drinking water pipes may shorten the life expectancy of the pipes and have a detrimental effect on the water quality in the network. Water companies in The Netherlands use relatively simple techniques on a large scale to determine the extent of leaching and consequently the condition of AC pipes. These techniques increase insight into the life expectancy of the pipes and the condition of the total network. This insight is useful in decision making with regard to the maintenance of the network. Monitoring techniques have also been developed to determine the effects of corrosion on the water quality. The use of these techniques contributes to the formulation of a strategy for preventing further corrosion of cement-containing pipes and negative effects for consumers.
References


