TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

4-B/2015

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EXPERIMENTAL RESEARCH ON DETERIORATION OF DRINKING WATER QUALITY AFTER CEMENT MORTAR PIPE LINING

EKSPERYMENTALNE BADANIA NAD POGARSZANIEM JAKOŚCI WODY PITNEJ PO CEMENTOWANIU PRZEWODÓW WODOCIĄGOWYCH

A b s t r a c t

In the paper the results of experimental research on the deterioration of drinking water quality after cement mortar lining were presented. The experiments were conducted in the renovated water pipeline section in Cracow. Based on the results, the expected degree of leaching of the pollutants from cement mortar to drinking water for specified lengths and diameters of renovated pipes, as well as water velocities, was estimated.

Keywords: cement mortar lining, water quality, water pipes

S t r e s z c z e n i e

W niniejszy artykule przedstawiono wyniki badań eksperymentalnych nad pogarszaniem się jakości wody do picia po cementowaniu przewodów wodociągowych. Pomiary przeprowadzono na odcinku jednej z krakowskich magistral poddanemu renowacji z zastosowaniem wykładziny cementowej. Na podstawie uzyskanych pomiarów przeanalizowano jakiego stopnia ługowania zanieczyszczeń z powłoki cementowej do wody można się spodziewać przy określonych długościach i średnicach przewodów poddanych renowacji oraz prędkościach przepływającej wody.

Słowa kluczowe: cementowanie, jakość wody, przewody wodociągowe

DOI: 10.4467/2353737XCT.15.406.5037

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1. Introduction

One of the most commonly used trenchless water pipe renovation methods is cement mortar lining. It is mainly used for steel and cast iron pipes. This method is performed, after thorough cleaning, by the spraying of cement mortar onto the inner surface of the pipeline. A rotary head, which is pulled through the pipeline at a constant speed, is used for spreading the cement mortar inside the pipe during renovation [1, 2], which provides a uniform layer of cement mortar. In turn, the cementation of new pipes during manufacturing in a factory is a different process. During the cementation the pipe rotates rapidly around its own axis. It provides a much smoother surface of coating than in the case of cement mortar lining made directly on a building site. Moreover, the rotation of the pipe around its own axis causes the movement of sand grains towards the pipe wall. In consequence, the fine-grained structure of cement mortar characterised by low seepage is formed [3]. The final thickness of the cement coating should be in the range between 3 mm and 10 mm. The coating thickness dependents on the pipe material and its diameter [4].

The popularity of cement mortar lining technique is due to its simplicity and relatively low costs. Additionally, the method is characterised by a quite short renovation time, guaranteeing a minimal interruption of water supply to the consumers. Cementing provides two form of protection against corrosion: active and passive. It also protects the pipe by an encrusting and void-filling calcite phenomenon. Therefore, renovation by cement spraying is considered to be a very effective method for solving drinking water quality problems in the long term [5, 6]. Active corrosion protection is provided by a very thin layer of water (a few micrometers) which is formed between the cement coating and the pipe wall. This layer has a very high pH at which the corrosion process is reduced or avoided [7].

However, it is often noted that directly after cement mortar spraying some of the drinking water quality parameters may deteriorate. In the case of soft water, which has a low content of carbonate and bicarbonate, contact of water with a newly applied cement coating may lead to leaching of calcium hydroxide – a component of the cement lining. It causes an increase in the pH of water and a decrease in the mechanical strength of the protective coating [7]. In turn, high values of pH can contribute to the dissolution and leaching of aluminium and chrome from the cement mortar into the water [8] and also other chemical elements such as lead, zinc, nickel, arsenic, cadmium, vanadium and copper. The amount of leached chemical elements from the concrete coating into the water depends on the type of applied cement. For example, use of high alumina cement contributes to the leaching of a significant quantity of aluminium into the water. In the case of high-calcium cements, leaching of large amount of calcium from the coating into the water is observed and, as a consequence, a significant rise of water pH [9].

Pipe diameter is another parameter that is significant for determining the concentration of chemical elements in the water after contact with the cement mortar coating in the pipeline. The volume of the circular pipe section rises proportionally to the square of the inner pipeline diameter, while the inner wall surface of the pipe section rises only proportionally to the diameter. Therefore, the larger the pipe diameter, the smaller the volume of water per cement mortar unit surface area (Fig. 1), consequently the larger the pipe diameter, the smaller the influence of the cement mortar on the water quality [10].

The impact of the cement mortar lining on the deterioration of drinking water quality in a short period after renovation was analysed in the paper. Full-scale experiments were conducted soon after renovation of water main section in Cracow. soon after renovation of the water main section of the water distribution network in Cracow. pH, alkalinity, concentration of calcium, aluminium and heavy metals such as chromium, lead and cadmium were measured in water samples collected before and after the newly renovated pipeline. Based on the results of the experimental research, the expected degree of leaching of pollutants from the cement mortar into the drinking water for specified lengths, diameters of renovated pipes and also water velocities was estimated.

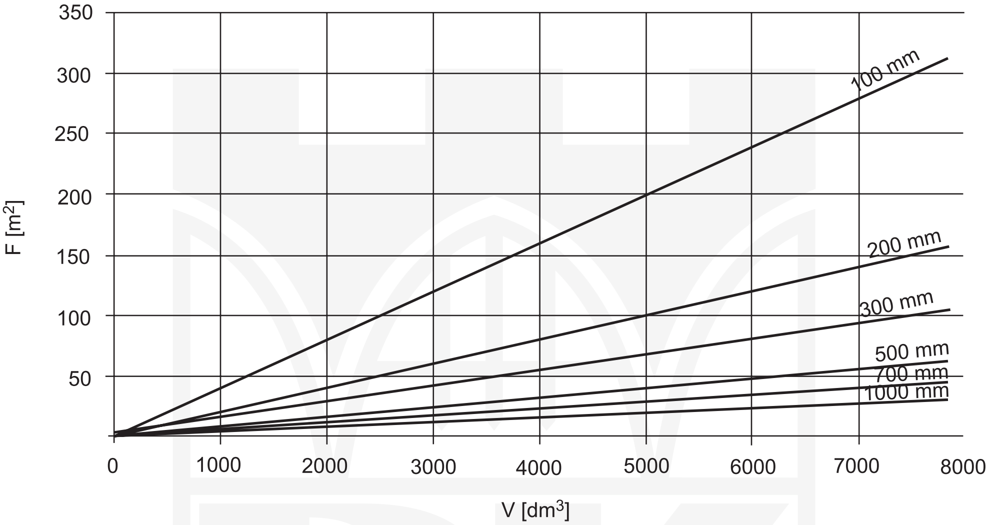

Fig. 1. The dependence of the water volume on the coating surface for few different pipeline diameters

2. Material and methods

The renovated water main section is located along one of the main streets in Cracow. The 500 mm diameter pipeline is made of steel and is 725 metres long. In a place where the pipeline passes under the road, a 110.5 metres-long section was renovated by cured-in-place pipe method in which a resin-saturated felt tube made of polyester and nylon fibers was pulled into the corroded pipe. The rest of the 614.5 metres of water main was renovated by cement mortar lining. The process of renovation was preceded by hydrodynamic cleaning with the aim of removal of accumulated pollution and corrosion products. Cleaning equipment powered by a water pump produced a pressure of discharge water of almost 100 MPa. The cement mortar lining process was conducted by centrifugal spreading of cement mortar on the inner surface of the pipe using a rotary head (Fig. 2). The cement coating thickness was equal to approximately 10 mm. The expected thickness of cement lining was achieved by providing a constant flow of cement mortar from the rotary head and its constant rotation speed and suitable rate of movement of the spraying equipment along the water pipe.

Fig. 2. Rotary head for cement mortar lining water pipes (author's photo)

For the preparation of the cement mortar, Portland cement CEM I 42.5 R – manufactured by CEMEX – was mixed with quartz sand in a ratio of 1 to 1. Next, water was added to the mixture, maintaining quite a low water-to-cement ratio equal to 0.35. After the completion of the cement mortar lining, one day of curing the cement mortar is required. After this time, the renovated pipe was filled with water and the water was kept for 6 days under working pressure. After this period of time a pressure test was conducted. For half an hour the water pressure was maintained at 10 bars. At the end the pipe was flushed with a velocity of 0.2 m/s for 6 hours before returning to usage.

3. Results

Water samples were collected before, during and 5 hours after flushing at the inflow to (sample No. 1) and the outflow from (samples No. 2-5) the renovated section of pipeline. The temperature of the collected samples was around 5°C. Each of the samples was tested in the lab for pH, alkalinity and concentration of chemical elements such as aluminium, chromium, calcium, cadmium and lead. The results of the pH and alkalinity tests are presented in Table 1. After half an hour from the start of the pipe flushing, the pH increased above 10 but decreased for the next ten hours, reaching a value of 9 at the end. It is supposed that this increase of pH was due to the impact of the fresh cement lining on the water. However, quite a quick decrease of pH after a few hours is probably caused by the 6 days of water retention which preceded the flushing and also the relatively large diameter and short length of the cemented pipe. In other cases pH is expected to exceed 9.5 – the limitation value for drinking water in the Polish Ministry of Health Regulation [11].

Concentrations of aluminium, calcium and heavy metals such as chromium, cadmium and lead in the collected samples are presented in Table 2. Concentrations of heavy metals were all under instrument detection limits, so it can be stated that the risk of drinking water contamination by leaching of heavy metals from fresh cement mortar lining seems to be negligible under the investigated conditions. Only a high increase of aluminium concentration, significantly exceeding the maximum limitation predicted by the Polish Health Ministry Regulation [11] and [12] (0.2 mg/l), was observed soon after the beginning of the flush. The aluminium concentration gradually decreased and, 5 hours after flushing, reached the same value at the beginning of the renovated pipe as at the end. Since during flushing the aluminium concentration was kept around the standard limitation, there is the potential risk of exceeding this value under other renovation conditions such as a smaller diameter, longer pipe, different cement, water quality and velocity, shorter flushing or omitting, preceded flushing, and six days retention time. The analysis of calcium shows a small increase in concentration at the beginning of the flushing process and a gradual decrease until the end. There is no significant influence on water quality in the short period but long-term leaching of calcium can devastate the mortar cement coating layer

Table 1

pH and alkalinity in collected water samples

No.	Sampling place	The time from the start of water pipe flushing [h]	pH	Alkalinity [mmol/l]
1	Inflow to the renovated pipe		7.75	1.20
2	Outflow from the renovated pipe	0,5	10.13	0.85
3		3	8.40	1.40
4		6	8.10	1.40
5		11	9.05	1.20

Table 2

Concentrations of chemical elements in collected water samples

No.	Sampling place	The time from the start water pipe flushing [h]	Aluminium [mg/l]	Chromium [mg/l]	Calcium [mg/l]	Cadmium [mg/l]	Lead [mg/l]
1	Inflow to the renovated pipe	0	0.043	< 0,002	61.44	< 0.001	< 0.005
2	Outflow from the renovated pipe	0,5	0.064	< 0,002	21.02	< 0.001	< 0.005
3		3	0.293	< 0,002	61.72	< 0.001	< 0.005
4		6	0.172	< 0,002	64.23	< 0.001	0.007
5		11	0.052	< 0,002	46.33	< 0.001	< 0.005

It was considered, based on the experiments, that the greatest risk of drinking water quality contamination in the short term after cement mortar lining renovation is due to aluminium leaching. Based on the experimental measurements presented in Table 2, growth of aluminium concentrations at the end of the freshly cemented pipe were calculated for different possible flow velocities, pipe lengths and diameters. The results of the calculations are presented in Figures 3 and 4. The calculations took into account preceded flushing, 6 days water retention, pressure test and 6 hours of flush. Figure 3 presents the results of the calculation for water drinking flow velocity equal to 0.5 m/s, and Figure 4 presents the results for 1.0 m/s velocity.

Growth in aluminium concentration increases proportionally to the length of cement mortar lined pipe and decreases proportionally to the pipe diameter. So, the smaller the diameter and the longer the renovated pipe, the greater the risk of pollutant leaching from the cement mortar into the water. The higher the velocity of water in the pipeline, the shorter the contact time with the cement coating. The shorter the contact time with the cement coating, the smaller the growth of aluminum concentration. So, the higher the water velocity, the smaller the growth of aluminum concentration. In Figures 3 and 4, two velocities, 0.5 m/s and 1.0 m/s, were taken into account. Assuming an inversely proportional dependence between water velocity and growth in aluminum concentration, a two times smaller growth in aluminium concentration for 1.0 m/s velocity is expected than for 0.5 m/s.

Since the maximum limitation of aluminum concentration in drinking water based on [12] is equal to 0.2 mg/l, a growth in concentration equalling 0.1 mg/l appears to be dangerous and should not be allowed. For 0.5 m/s velocity, such a high growth of aluminium is expected to appear if a 200 mm diameter pipe is a minimum 3 km long, or if a 500 mm diameter pipe is more than 8 km long. Of course, allowable growth in aluminium concentration depends on the aluminium concentration in the water produced by the treatment plant and the flushing time period.

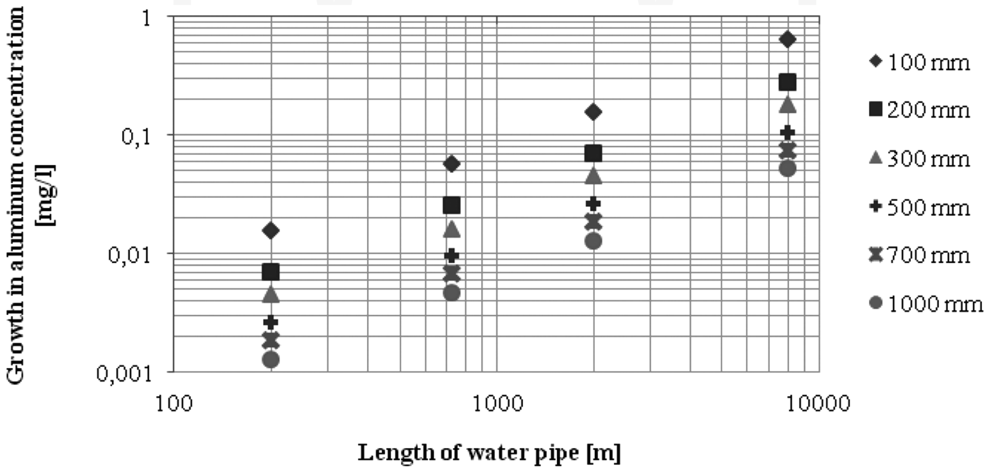

Fig. 3. Growth in aluminum concentration depending on the length and diameter of a freshly renovated cement mortar lined pipe for 0.5 m/s velocity

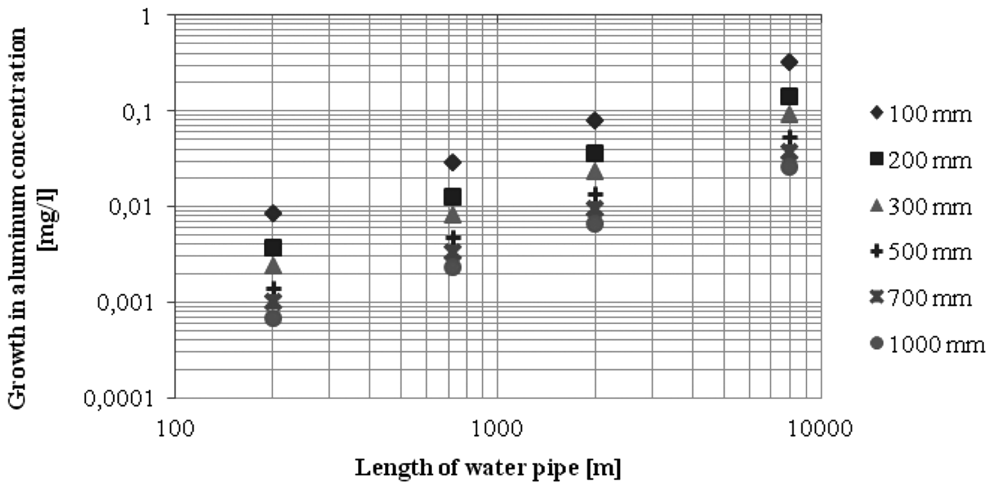

Fig. 4. Growth in aluminum concentration depending on the length and diameter of a freshly renovated cement mortar lined pipe for 1.0 m/s velocity

4. Conclusions

Despite cement mortar lining of water pipes being a common method of renovation due to its many advantages, it was noted that, directly after application of the cement mortar inside the pipeline, some quality parameters of drinking water may deteriorate. The results of experimental research performed on a steel water pipe section with a diameter of 500 mm and length of 725 m shows that the greatest risk of deterioration in water quality is related to the increase in pH value and leaching of aluminium from the cement mortar into the water. Under experimental conditions it was observed that the risk of water contamination by chemical elements as chromium, lead or cadmium is negligible.

Based on the conducted experiments it was possible to estimate the potential growth of aluminium concentration after cement mortar lining for different pipe lengths and diameters at velocities of 0.5 m/s and 1.0 m/s. Calculations were conducted based on contact time, assuming linear direct dependence of leached metals growth on pipe length and linear reversely proportional dependence on pipe diameter and water flow velocity.

Based on the experimental measurements and calculations, growth in aluminium concentration exceeding 0.1 mg/l is probable if the renovated 500 mm diameter pipe is a minimum 8 kilometres long and water flow velocity is not faster than 0.5 m/s for the same as the experimental conditions other than pipe diameter, length and velocity.

The curves showing the growth of aluminum concentration in drinking water after contact with the freshly cemented pipes enable finding of the maximum length of water pipe characterised by a specific diameter that can be once renovated without the risk of leaching aluminium from the cement mortar into the water exceeding the aluminum concentration limit for drinking water.

Acknowledgment

The research has been financed by Polish National Science Center under the research project No 2648/B/T02/2010/39.

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