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Cement Mortar Lining as a Potential Source of Water Contamination

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Abstract**—**Several different cements have been tested to evaluate their potential to leach calcium, chromium and aluminum ions in soft water environment. The research allows comparing some different cements in order to the potential risk of water contamination. This can be done only in the same environment. To reach the results in reasonable short time intervals and to make heavy metals measurements with high accuracy, demineralized water was used. In this case the conditions of experiments are far away from the water supply practice, but short time experiments and measurably high concentrations of elements in the water solution are an important advantage. Moreover leaching mechanisms can be recognized, our experiments reported here refer to this kind of cements evaluation.

Keywords**—**Concrete corrosion, hydrogen sulfide, odors, reinforced concrete sewers, sewerage.

I. Introduction

It is important to realize that many renovation methods successfully applied in sewerage are too expensive for water supply systems. This can be simply explained by deeper burial of sanitary sewers and by constructing them below roads while large diameter water mains usually go through green areas and small diameter water pipes go under pavements. Neither demolitions of road surface nor new organizations of road traffic are usually necessary for renovating of water mains. Because of this, only the cheapest methods of renovation are usually utilized for water pipes. The first method is cement mortar lining [1] and the second epoxy spray lining. These two methods are substantially different. Epoxy resin and polyurethane linings adhere strongly to the metal creating a mechanical barrier against diffusion of oxygen and ions. The mortar lining does not attach strongly to the pipe surface. This can be observed in Fig. 1. There is a thin layer of water between the lining and ductile iron. The pH of this water should be between 11 and 13, which is high enough to stop electrochemical corrosion processes. New ductile iron pipes are covered on the inside by cement mortal lining, except small diameter pipes produced for transporting soft waters with low alkalinity. In these unwanted circumstances mechanical protection is chosen. Recently mechanical protection by thin epoxy resin has become a more common choice for renovation of old cast iron pipes because the epoxy adhesive is thinner in comparison with conventional cement mortar lining without additives and does not require time for curing, tightening and surface smoothing. However, properly done cement mortar lining creates relatively low friction losses for water flow and its roughness does not increase rapidly resulting in stable or very slow deterioration of flow conditions during the time [2]. Some of the inconveniences of applying mortar lining are a high pH value and a raised concentration of calcium, aluminum and chromium [3], [4], usually in a short time after cast iron cementing or applying new ductile iron pipes, protected inside by cement mortar lining. In long periods of time, lining reduces number of complaints on the quality of drinking water.

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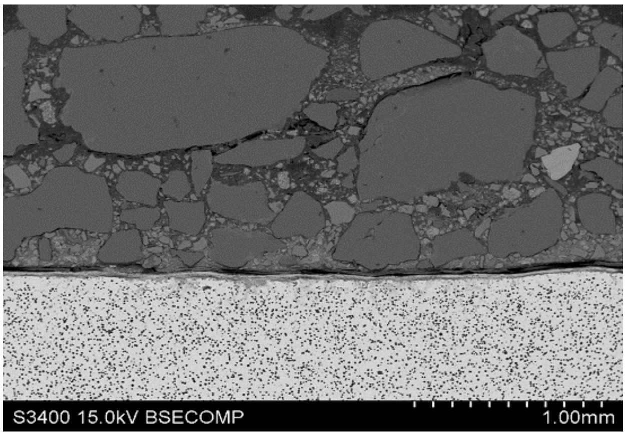

Fig. 1 A part of a cross section through a ductile iron pipe wall showing the bottom of cement mortar coating and the top of ductile iron cross section. A gap of a few micrometers is highly visible between the metal and the cement mortar lining

II. Properties of Lining

Cement mortar lining produced in factory differs significantly from mortar lining done in the fields. In the first case, it does not matter whether centrifugal lining or spraying is applied. Fast rotation of the pipe sprays the mortar homogeneously and compacts it by the centrifugal force. In this case the inside surface of the mortar is smooth, the porosity of the whole layer is very small and the roughness of the internal surface is quite small. Sand grains are pressed by the centrifugal force towards the pipe's internal wall surface while cement, in reaction with water, forms smooth surface of low permeability.

Cementing of pipes in the field differs significantly from the two methods to be applied in the foundry. In the field after cleaning the pipe, the boom radial spray system is inserted and moves with a constant speed along the pipe ax. The head of the system rotates rapidly spraying the mortar over the whole perimeter of a pipe. The centrifugal force is used to spray but not to compact the mortar and to move sand grains towards the metal. This results in much more homogeneous lining. Well compacted heterogeneous cement mortar is presented in Fig. 2. In Fig. 3, a cross section through mortar lining sprayed in the field is presented. All photographs have been made using a scanning electron microscope, Hitachi S-3400N.

Fig. 2 Cross section through cement mortar lining done by the spraying method

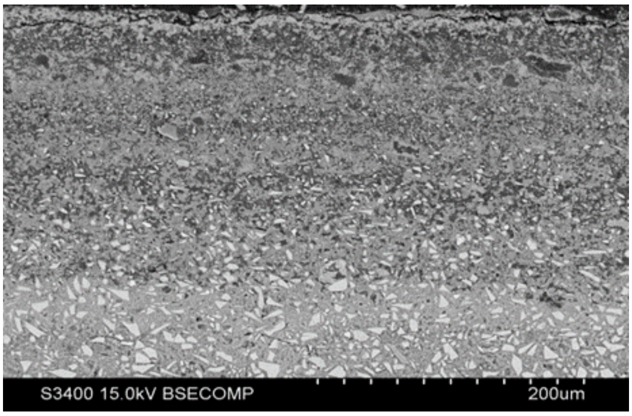

Fig. 3 A cross section through a mortar

Electron scanning microscope is also useful for investigating the extent to which the mortar lining deteriorates in time. Concrete contains up to 1% by weight of calcium hydroxide. If the Langelier Saturation Index [5], [6] of water transported through pipes is negative the calcium hydroxide dissolves in water. Losing calcium makes the lining less protective against corrosion because of lowering of the pH value in the thin layer of water between the mortar and the internal pipe wall. Back scattered electrons (BSE) give a clear picture of the deteriorated area. Elements with higher atomic number backscatter beam electrons more efficiently than elements of low atomic number, so the first appears brighter in the image. Calcium and aluminum are elements with high atomic numbers in comparison to most other elements present in mortar lining so the deteriorated areas from which calcium and aluminum were washed out appear dark in the image.

In this way BSE photographs distinct areas of different chemical compositions, but the energy dispersive X-ray spectroscopy (EDS) was used to receive more detailed information about the chemical content of mortar lining in the cross section of mortar sample surface and in a few micrometers below. This method is not applicable for the first five elements with the lowest atomic numbers and the concentration of carbon is usually overestimated.

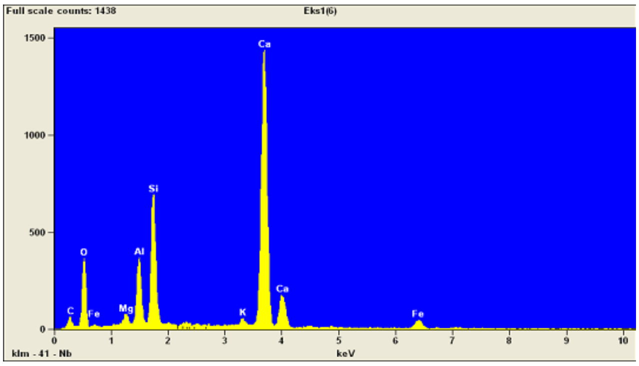

Fig. 4 An example of mortar lining surface analyze by the EDS method

An example of the energy dispersive X-ray spectroscopy analysis is presented in Fig. 4. High content of aluminum in cement mortar is positive for protection properties of the lining [7] but simultaneously may lead to higher concentrations of aluminum in water flowing through freshly renovated pipes from cast iron or through new ductile iron water mains. The buffer capacity of flowing water and the chemical composition of cement mortar are not the only important factors in water contamination by aluminum. The diameter of a pipe is also important. The inside surface area is proportional to a pipe's radius while the volume of water filling a pipe is proportional to the radius to the second power. In other words, the internal mortar lining surface per unit volume of flowing water is inversely proportional to the radius of the pipe. Hence, the impact of leaching calcium on pH and leaching of the aluminum from mortar to the water is well visible in pipes of small diameters.

III. Methodology

Two different methods are to be used to answer two different questions. The first question refers to the comparison between cements in respect to the risk of water contamination by aluminum. This question is considered in the present paper. The Netherlands Normalization Institute Standard EA NEN 7375:2004 gives the answer to this kind of questions. However, it may not be used to evaluate the risk existing in a real situation. To answer the questions referring to the real risk in a given situation, it is necessary to use the same kind of water that is transported by pipes. In contrast, the EA NEN 7375:2004 standard [8] requires that mortar samples are kept in demineralized water. In this way the strongly aggressive water environment is the same for all mortar samples. Because of the strong aggressiveness of demineralized water against concrete, several samples of water can be collected with measurably high concentrations of calcium, aluminum and chromium in periods from six hours to 64 days of the experiment. Mortar samples have been prepared from cement solutions in water in the proportion 0,4 of water to cement by weight. Clean silica sand sieve curves fulfilled both standards. Mortar samples of the volume 0,139 dm3 and the total outside surface 2,3dm2 were kept in demineralized water of the 0,45dm3. For each one dm2 of the mortar samples surface, there was 0,2dm3 of demineralized water which is adequate water volume corresponding to one dm2 of mortar lining in a pipe with an 80mm inside diameter. The water was replaced after 6h, 27h, 54h, 98,5h, 216,5h, 585h, and 1657h. Each time the same volume of demineralized water was used but the samples remained the same. For the whole 64 days the temperature was kept constant and equal to 19C. Concentrations of calcium, aluminum, lead and the value of pH were measured each time. Because of the space limitation only the results of Aluminum concentrations are reported for now. Five cements have been tested. Two of them (Gorkal 70 and Gorkal 40) were quick – setting and high – alumina cements of improved resistance to corrosion and the concentrations of aluminum oxides were 70% and 40% by weight respectively. The Portland cement CEM I consisted of clean clinker in at least 95%. The next two Portland cements, CEM II and CEM II/B-W, contain fly ash rich in calcium of 35% by weight (CEM II) and multicomponent cement CEM II/B-M (V-LL) 32,5R contains fly ash of silica and calcium origin in the content of 21% to 35%.

IV. Results

The results of pH measurements just before replacing the demineralized waters are presented in Table I and the concentrations of aluminum in water are presented in Table II.

TABLE I
RESULTS OF PH MEASUREMENTS AFTER GIVEN PERIODS OF TIME

Period of time after which samples were collected [d]	Type of cement				
	Gorkal 70	Gorkal 40	CEM I	CEM II/B-W	CEM II/B-M (V-LL) 32,5R
0 – 0.25	11.2	11.9	11.9	12.32	12.22
0.25 – 1.1	12.2	11.92	12.31	12.34	12.35
1.1 – 2.2	11.59	11.64	12.31	12.26	12.31
2.2 – 4.1	11.43	11.65	12.23	12.26	12.31
4.1 – 9.0	11.46	11.7	12.28	12.24	12.35
9.0 – 16.0	11.48	11.73	12.27	12.11	12.27
16.0 – 36.0	11.62	11.8	12.08	12.24	12.28

TABLE II
CONCENTRATIONS OF ALUMINUM IN DEMINERALIZED WATER SAMPLES AFTER GIVEN PERIODS OF TIME, JUST BEFORE REPLACING THEM [MG/L]

Period of time after which samples were collected [d]	Type of cement				
	Gorkal 70	Gorkal 40	CEM I	CEM II/B-W	CEM II/B-M (V-LL) 32,5R
0 – 0.25	137,4	99,1	34,5	0,552	0,457
0.25 – 1.1	89,1	203,6	13,6	1,53	1,47
1.1 – 2.2	218,4	109,1	4,53	1,72	1,47
2.2 – 4.1	139,8	90,2	3,06	2,24	1,85
4.1 – 9.0	145,5	101,3	3,65	3,19	2,52
9.0 – 16.0.	120,2	98,5	2,98	2,73	2,38
16.0 – 36.0	88,8	100,1	9,12	2,98	2,71
36.0 – 69.0	73,8	97,3	1,92	2,78	1,98

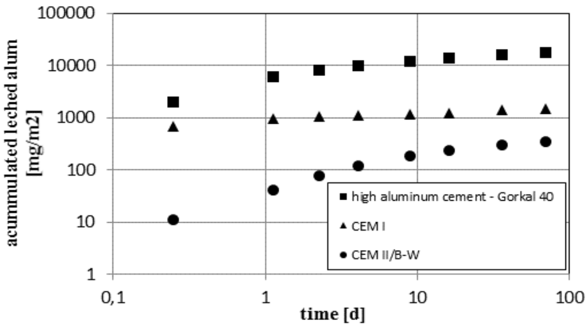

Fig. 5 Cumulative concentrations of Aluminum in demineralized water being replaced after periods specified in Tables I and II

From the values of aluminum concentrations measured after each period specified in Tables I and II the cumulative concentrations were calculated and are presented in Fig. 1. According to the EA NEN 7375:2004 standard, some calculations for predicting aluminum leaching mechanisms were also done. They suggest that the transfer of aluminum to water is controlled first by solubility and diffusion from high-alumina cements, but then the amount of aluminum on the mortar surface existed, while the leaching still remained substantial. For CEM I, first the leaching of aluminum was stimulated by washing out but after two weeks diffusion took control. For CEM II, at the beginning the diffusion was the predominant process but after 2 weeks the surface content of aluminum became low.

V. Results Analyses and Conclusions

1) Through the whole test leaching of aluminum from high–alumina cements was more substantial than from the others.
2) The standard EA NEN 7375:2004 fulfills two requirements. It allows the comparison of different cements in respect to leaching of aluminum in the same extreme conditions and the description of mechanisms of leaching. In spite of the fact that it is not to be applied in known real environments the results indicate potential problems with putting a long pipe freshly renovated by cement mortar lining into service immediately after 24 hours of washing and after the required disinfection, if the transported water is extraordinary soft.

3) High pH values of demineralized water being in contact with cement mortar samples resulted in very high aluminum content in water. After four days, in a 6-hours test, the leaching still gave an one hundred times higher concentration of aluminum than allowed by WHO and EU standards for drinking water. For the cement CEM I, it was 3 times higher and 2 times higher for CEM II.
4) The result of calculations suggests that the transfer of aluminum to water is controlled first by solubility and diffusion from high-alumina cements, but then the amount of aluminum on the mortar surface existed, while the leaching still remained substantial. For CEM I, the leaching of aluminum was first stimulated by washing out but after two weeks diffusion took control. For CEM II at the beginning the diffusion was the predominant process but after 2 weeks the surface content of aluminum became low.
5) Pipe producers usually do not know the place of their products application but it seems strange that the standards referring to pipe cementing in the field do not consider transported water chemistry which is well known.

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