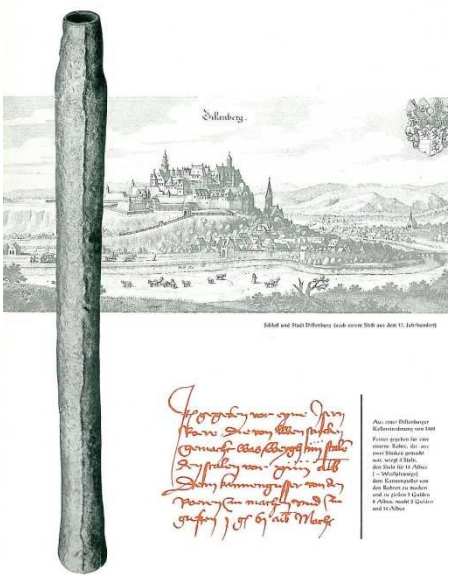
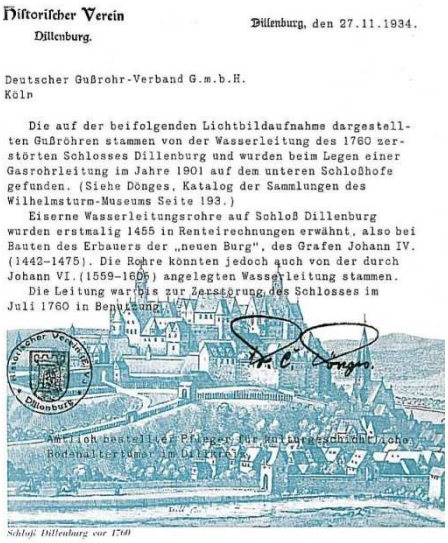
"Sustainable corrosion protection of cast iron pipes by cement mortar lining considering the existing water quality"

By Stephan HOBOHM, Duktus Rohrsysteme Wetzlar GmbH, Germany

Cast iron pipes were already being used for the supply of water around 600 years ago. One of the first examples of the use of cast iron pipes is Dillenburg Castle's drinking water supply. This is thought to have been set up in 1455 and was in operation until the castle was destroyed in 1760 (see picture 1).




Historischer Verein
Dillenburg.

Dillenburg, den 27.11.1934.

Deutscher Gußrohr-Verband G.m.b.H.
Köln

Die auf der beifolgenden Lichtbildaufnahme dargestellten Gußröhren stammen von der Wasserleitung des 1760 zerstörten Schlosses Dillenburg und wurden beim Legen einer Gasrohrleitung im Jahre 1901 auf dem unteren Schloßhofe gefunden. (Siehe Dönges, Katalog der Sammlungen des Wilhelmsturm-Museums Seite 193.)

Eiserne Wasserleitungsrohre auf Schloß Dillenburg wurden erstmalig 1455 in Renteirechnungen erwähnt, also bei Bauten des Erbauers der „neuen Burg", des Grafen Johann IV. (1442–1475). Die Rohre könnten jedoch auch von der durch Johann VI. (1559–1606) angelegten Wasserleitung stammen.

Die Leitung war bis zur Zerstörung des Schlosses im Juli 1760 in Benutzung.

Schloß Dillenburg vor 1760

Picture 1

These pipes were still made of grey cast iron and had no inner or outer coating at all. Evidently, therefore, under certain installation and operating conditions a cast iron pipe can perform its services for many hundreds of years even without any inner or outer coating.

It was not until about 100 years ago that people began to coat cast iron pipes. What they used to do this was tar and later bitumen. These first attempts at a form of passive corrosion protection were, however, not very effective. Deposits of iron or manganese, some solid, still used to keep forming, especially inside drinking water pipes. These incrustations led to significant hydraulic losses and even to the complete blocking of the pipe. Any abrupt increase in flow speed, as can happen for example when a water pipe bursts, could and can lead to the familiar brownish 'rusty water'. Under certain operating conditions and with certain qualities of water it is moreover not possible for protective layers to form, as a result of which corrosion can occur. Picture 2 shows the inside of a grey cast iron pipe from c. 1930 with slight incrustations. No corrosion damage can be seen. This pipe was in use for around 80 years.

Picture 2

Around 1965, the first experiments began with cast iron pipes lined as standard at the factory with cement mortar. Since c. 1975, all cast iron pipes made in Germany have been furnished with a cement mortar lining. At about the same time the raw material was changed from grey cast iron to ductile cast iron, which also resulted in changes to the outer coating. Ductile cast iron pipes have since then been zinc plated on the outside to DIN EN 545 [1] and coated with a top coat (bitumen – later epoxy) or a cement mortar cover. The long-term protective effect of cement mortar covers is, however, not the subject of this paper [2].

The aim in what follows is to describe the lasting protective effect of cement mortar linings based on the example of a drinking water pipeline that has been in use for c. 40 years.

The composition, application method and areas of use of any cement mortar lining are based on DIN 2880 [3]. Pursuant to this there are three available methods for applying the lining.

- Method I → Rotating centrifuge method
- Method II → Centrifugal head method
- Method III → Manual lining

In the case of cast iron pipes the cement mortar lining is usually applied at the factory by method I or II or by a combination of both. Method III (application by hand) is used for fittings and repairs. According to DIN 2880 the lining method should have no influence on the cement mortar lining's durability as long as the same values are achieved for the water/cement ratio and the mix ratio. However, it can be assumed that method I leads to the greatest compaction and the least porosity. It is above all the porosity that ultimately has a key influence on the speed of carbonation.

The cement mortar used for drinking water pipes is usually a Portland or blast furnace cement. However, for aggressive forms of water, such as effluent, surface water or untreated water, a high-alumina cement can also be used. The layer thickness of the cement mortar lining varies depending on nominal width from 4 to 9 millimetres (see table 1).

[1] Ductile iron pipes, fittings, accessories and their joints for water pipelines – Requirements and test methods - English translation of DIN EN 545:2011-09
[2] Examination of ductile iron pipes with cement mortar coating after a period of three decades in operation: FGR – Annual Report 45
[3] Use of cement mortar lining for cast iron pipes, steel pipes and fittings: DIN 2880

DN	Layer thickness [mm]	
	Nominal value	min. value
40 to 300	4	2.5
350 to 600	5	3
700 to 1200	6	3.5
1400 to 2000	9	6

Table 1

After now over 40 years of factory-applied cement mortar linings the question arises as to whether such a thin lining, just a few millimetres thick, can provide effective and sustained protection against corrosion over the long term as well.

In order to be able to carry out an appropriate investigation, it was necessary to acquire a section of drinking water pipe that had been in use for several decades and that originated from the early years of production with cement mortar linings. The pipe section examined for this purpose comes from 1975 and at the time of being examined had thus been in use for 39 years.

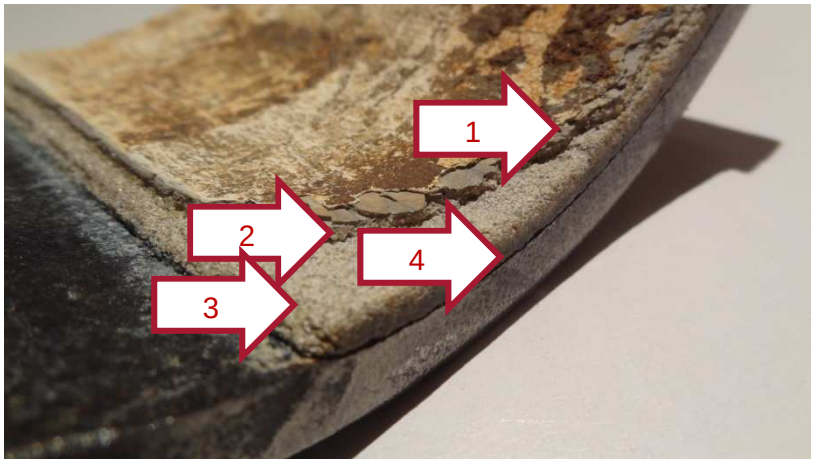
The medium flowing through it was drinking water in lime/carbonic acid equilibrium. The calcite solubility was accordingly nil and any sanding or abrasion of the cement mortar lining was not to be expected. With an M-value of 1.35 the buffering can be classified as low to medium. The level of free CO_2 content was c. 0.5mg/l. It is a cement mortar lining based on blast furnace cement that was applied by method I.

The structure of the cement mortar coating is made up of four relatively clearly distinguishable layers:

1. Slurry layer (water side) - Layer 1
2. Cement layer - Layer 2
3. Cement layer, containing aggregate - Layer 3
4. Cement layer, containing aggregate - Layer 4

These four different layers are caused by the application method.

The rotation of the pipe in method I generates centrifugal forces, which drive the heavy components (gravel) towards the pipe wall, while the fine and lightweight elements (cement particles and mixing water) get moved inwards towards the pipe axis (see picture 3).



Applied in this way the cement mortar lining forms the passive corrosion protection, the effectiveness of which is largely based on the raising of the pH-value to values ≥ 12 between lining and pipe wall. This increase in pH-value is caused by the porosity of the cement mortar lining and the water that penetrates as a result. This phenomenon has already been described at length in various scientific articles.[4]

The question arises, however, as to how long this passivation of the cast iron pipe surface actually lasts. Does the increase in pH-value needed for reliable corrosion protection still exist decades or even hundreds of years later?

In order to answer this question, the existing 39-year-old cement mortar lining was taken off - layer by layer - and examined in respect of its content of calcium carbonate ($CaCO_3$), free lime (CaO) and total carbonate (CO_3). The results are summarised in table 2. Picture 3

	Carbonat (CO_3)	$CaCO_3$	Freikalk	Carbinatisierungsgrad
Schicht 1	Gesamtcarbonat 58%	Calciumcarbonat 79%	Freikalk 0	Carbonatisierungsgrad 100 %
Schicht 2	Gesamtcarbonat 12,7 %	Calciumcarbonat 21,2 %	Freikalk 13%	Carbonatisierungsgrad 47 %
Schicht 3	Gesamtcarbonat 5,6 %	Calciumcarbonat 9,3 %	Freikalk 1,7 %	Carbonatisierungsgrad 77 %
Schicht 4	Gesamtcarbonat 2,4 %	Calciumcarbonat 4,0 %	Freikalk 9,0 %	Carbonatisierungsgrad 20 %

Table 2

The cement stone of layer 1 is completely carbonated. There is no longer any pH-value influencing taking place in this area.

Layer 2 shows only relatively low calcium carbonation.

The carbonation of layers 3 and 4 largely matches that of the original cement mortar and is due to the calcite in the sand fraction.

The carbonation of layer 1 and the associated increase in volume has led to a closure of the pores originally existing in this layer. This greatly slows down and potentially even practically stops any water exchange and any further carbonation of layers 2 to 4. In addition to this there are also:

- the in any case already very low proportion of pores (caused by method I),
- the mortar's very high moisture penetration → 100%, as it is laid inside a drinking water pipeline (the speed of carbonation is highest at a moisture level of 50 to 70%)
- and the low water-cement value of the mortar used.

All four factors taken together let it be concluded that with the given water quality a cement mortar lining's active corrosion protection will remain intact far into the future. Based on current levels of knowledge it is not possible to foresee any limitation of the service life.

This assessment is reinforced by a visual examination of the cast iron pipe surface underneath the cement mortar lining. Even after 39 years of use no signs of any corrosion at all could be identified (see picture 4).

[4] Cement-mortar linings for ferrous-material pipes - Part 1: Physical and corrosion-chemical aspects: 3R international (43) issue 10/2004 or Characteristics and proven value of cement-mortar linings in cast iron pressure pipes: FGR – annual report 4

Picture 4