

# Experts report on the performance of reinforced concrete surfaces cast using Zemdrain® formwork liners in wastewater treatment plants after ten years of operation.

## 1. Reinforced concrete structures in municipal wastewater treatment plants

For more than 50 years, the FEhS Institut für Baustoff-Forschung e. V. has been making evaluations of concrete technologies, especially those related to structures made of reinforced or prestressed concrete in aggressive environments. This institute is involved with such structures from the planning phase through to their completion. Due to the numerous activities that the FEhS carries out in parallel with construction projects, especially in the field of wastewater treatment plants, the Institute has developed concrete mixes for new wastewater treatment plant construction projects. The durability of the constructed structures is subsequently evaluated and assessed.

To guarantee the durability of reinforced concrete structures exposed to chemical and/or physical attack, special attention must be paid during concreting to the selection of the binding agent (cement), to the particle-size distribution curves of the aggregates, to the consistency of the “green” concrete and to subsequent curing regimes.

Density and strength of the concrete is of paramount importance in ensuring the quality of the outer concrete surface. Penetration of toxic liquid or gaseous substances must be completely excluded if possible. The depth of penetration should be kept to a minimum to minimize chemical attack on

the concrete surface and to the cover zone in general. The use of a high-quality binding agent (cement) and a low water/cement ratio (w/c) reliably provide for a high degree of density and compressive strength of the concrete. In addition to compressive strength, however, surface tensile strength of structures must also be sufficient to help reduce to an absolute minimum any concrete surface abrasion caused by water, suspended solids and weather exposure.

## 2. Surface concrete quality

Wastewater compositions as well as biological cleaning processes result in considerable chemical and/or physical attack on reinforced concrete structures.



**Picture 1:** Reinforced concrete structures at wastewater treatment plant Bonn-Beuel exposed to high chemical and/or physical attack.

A high-quality, extremely dense concrete surface becomes a must for any reinforced concrete structure, especially

when subject to attack by biogenous sulphuric acid. The water/cement ratio (w/c) plays a crucial role. A low water/cement ratio provides for a high degree of density and compressive strength of the concrete. Chemical attack on the concrete surface due to toxic substances, exposure to freeze/thaw cycles and concrete surface abrasion caused by water, suspended solids and weather exposure creates a need for a very dense and extremely solid concrete surface. Alternatively, it is possible to install a concrete surface protection system.

The relevant documentation and rules for concrete quality testing in Germany published by Bauberatung Zement and by DWA (German Association for Water, Wastewater and Waste), e.g. data sheet DWA-M 211 „Protection and repair of concrete structures in municipal wastewater treatment plants“, issue

April 2008, specify the requirements with regard to concrete used in wastewater treatment plants. Data sheet DWA-M 211 also describes in detail the expenses of the building owner and costs incurred for the repair of concrete spalling, corrosion damage at the reinforcement or spalling caused by frost. In this context it should be borne in mind that such repairs are not only costly, but they also cause operational downtimes and affect the composition of the treated wastewater during the operational downtime of the plant.

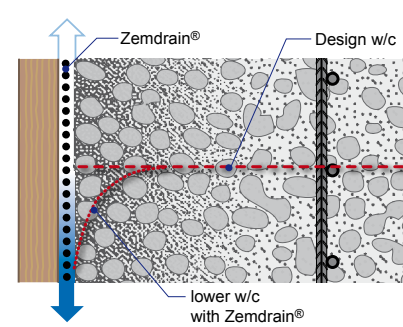
In order to considerably improve the quality of concrete surfaces the companies DuPont and Frank have developed a controlled permeability formwork liner which reduces the water/cement ratio in the outer surface of all concrete structures.

### 3. Controlled permeability formwork (CPF) liner

The controlled permeability formwork liner Zemdrain® is made from polypropylene fibres (PP) with different surface structure on each side and with controlled permeability. After direct application to the formwork, the liner as a result of vibrator movement filters excess mixing water out of the concrete surface. Air and excess water are collected on the textured outside of the polypropylene fabric (formwork side), whilst the smooth internal surface of the fabric which is oriented towards the concrete provides a dense and hard concrete surface. Formliners are turned to the outside at the base of

the formwork, so that excess water is drained away in a controlled manner as a result of gravity. This principle compacts finest concrete particles at the concrete surface and simultaneously reduces the w/c ratio in the surface concrete area to < 0.4.

Mixing water retained in the fabric of the liner is thus transported back to the concrete surface during the first few hours of “hydration” and this results in “additional early age concrete curing” at the beginning of the actual curing phase (quicker, more complete cement hydration).



**Fig. 1:** Functional description of controlled permeability formwork liner: Zemdrain® drains excess water and air out of the surface concrete zone and thus reduces the w/c ratio to an optimum value. Surface concrete thus becomes harder, denser and more durable.

### 4. Assessment of the quality of the concrete surfaces of wastewater structures constructed using Zemdrain®

In order to produce additional in-service evidence of how using a Zemdrain® formwork liner improves the outer surface quality and simultaneously improves the durability of concrete structures, the Building Material Institute of the FEhS Institute has examined, assessed and evaluated two typical structures. The concrete structures in these two wastewater treatment plants have been exposed to particularly aggressive environments since their construction some 10 years ago.

The two concrete structures examined were a nitrification basin in a wastewater treatment plant at Offenburg-Griesheim, and an activation basin in a wastewater treatment plant at Bonn-Beuel.

In order to be able to evaluate the concrete quality, the FEhS Institute obtained cores from the above-mentioned concrete structures, which were subsequently examined in certified test laboratories of the FEhS Institute.

Tests on the concrete quality of the above-mentioned structures were based on the following criteria:

- Concrete compressive strength
- Tensile strength of the outer concrete surface
- Freeze/thaw resistance.

Concrete cores were obtained from both structures and were in each case taken from zones permanently above and below the fluctuating water level.

At the Offenburg-Griesheim wastewater treatment plant it was also possible to compare cores taken from a Zemdrain® wall structure with cores taken from a wall structure, which was produced from the same concrete, however, without the use of

the formwork liner. This has enabled the Institute to provide an assessment of the comparative performance of concrete surfaces produced with and without the use of the formwork liner under identical conditions.

**Picture 2:** Offenburg-Griesheim: Core extraction locations at external wall and spillway wall



#### 4.1 Visual inspection of wastewater treatment plants under assessment

Visual inspection of the concrete surfaces revealed for both wastewater treatment plants a clear difference between surface qualities produced with and without the Zemdrain® formwork liner. Concrete surfaces produced without the formwork liner are much rougher and show slight abrasion of the fine cement layer. However, at the time of testing, concrete surfaces that have

been produced using the formwork liner, still feature the structure of the polypropylene fabric of the formwork liner. Picture 3 clearly depicts the difference between surface qualities produced with and without the Zemdrain® formwork liner after ten years of operation.

#### Concrete composition

Structures were made of concrete consistency class B35 to DIN 1045, version 1988. The maximum water/cement ratio (w/c) of the concrete was limited to 0.50. Portland cement and blast-furnace cement were used as binding agents.

#### 4.2 Test details and sampling

A total of 18 concrete cores were extracted at the nitrification basin at Offenburg-Griesheim and a total of 14 cores were extracted at the anaerobic activation basin at Bonn-Beuel. FEhS subsequently carried out the relevant technical tests on the concrete.



**Picture 3:** Concrete surfaces:  
 Right side:  
 External wall, surface was cast using Zemdrain®  
 Left side:  
 Spillway wall, surface was cast without using Zemdrain®

##### 4.2.1 Concrete compressive strength

Concrete compressive strength of the extracted concrete cores (cylinders) was determined to DIN EN 12504-1.

##### 4.2.2 Tensile strength of the outer concrete surface

Tensile strength of the cleaned concrete surfaces was determined to the standards of the DAfStb guideline "Protection and Maintenance of concrete structures", Part 3, Annex C, edition October 2001.

##### 4.2.3 Freeze/thaw resistance

Nine concrete cores were subject to alternating freeze/thaw test cycles. Alternating freeze/thaw test cycles were performed in a temperature-controlled freezer (air conditioned freezer) according to ZTV-Ing.

A total of 56 alternating freeze/thaw test cycles were carried out (CIF test).

**5. Assessment summary of test results**

Compressive strength test results for the concrete used in the nitrification basin at Offenburg-Griesheim range between 72 N/mm<sup>2</sup> and 106 N/mm<sup>2</sup>. It became especially evident that concrete structures, which are permanently submerged show a much higher

compressive strength than concrete samples taken from the area above the maximum water level.

The minimum requirement for both cases was concrete consistency class B35, to DIN 1045, version 1988.

Appropriate curing of the concrete was achieved by permanent humidification of the concrete and by the type of cement used for one structure. Test results are given in the attached Tables 1 and 2.

Designation Cylinder no.	Dimensions		Slenderness H/D	Weight kg	Apparent density kg/m <sup>3</sup>	Rupture load kN	Compressive strength N/mm <sup>2</sup>
	Height mm	Diameter mm					
O 1	96	94	1,02	1,668	2504	499	72
O 2	96	94	1,02	1,552	2330	464	67
O 6	95	94	1,01	1,624	2463	558	80
U 1	95	94	1,01	1,679	2547	641	92
U 2	96	94	1,02	1,691	2538	706	102
U 4	96	94	1,02	1,687	2532	739	106
M 2	96	94	1,02	1,680	2522	558	80
M 3	96	94	1,02	1,648	2474	589	85
M 6	95	94	1,01	1,628	2469	580	84

**Table 1: Concrete compressive strength values referring to cores from the nitrification basin at Offenburg-Griesheim.**

O 1, O 2, O 6 External wall, internal face above the maximum water level, surface was cast using Zemdrain®  
 U 1, U 2, U 4 External wall, internal face below the maximum water level, surface was cast using Zemdrain®  
 M 2, M 3, M 6 Spillway wall, below the water level, surface was cast without using Zemdrain®

Designation Cylinder no.	Dimensions		Slenderness H/D	Weight kg	Apparent density kg/m <sup>3</sup>	Rupture load kN	Compressive strength N/mm <sup>2</sup>
	Height mm	Diameter mm					
BK 3	105	104	1,01	2,109	2364	600	71
BK 6	96	96	1,00	1,792	2579	542	75
BK 10	97	97	1,00	1,709	2384	582	79
BK 11	96	96	1,00	1,726	2484	613	85
BK 13	96	97	0,99	1,818	2563	621	84

**Table 2: Concrete compressive strength values referring to cores from the anaerobic activation basin at Bonn-Beuel**

BK 3, BK 11 External wall, internal face above the maximum water level, surface was cast using Zemdrain®  
 BK 6, BK 10, BK 13 External wall, internal face below the maximum water level, surface was cast using Zemdrain®

Tests to determine the surface tensile strengths and after alternating freeze/thaw cycles the abrasion resistance of concrete surfaces were performed. Surface tensile strength values of concrete samples taken out of the nitrification basin at Offenburg-Griesheim range between a min. of 2.7 N/mm<sup>2</sup> up to max. 4.8 N/mm<sup>2</sup>, whereby only two out of nine test results are below a value of 3.0 N/mm<sup>2</sup>.

Tests on samples from the activation basin at Bonn-Beuel produce evidence of the same high quality of concrete surface. In this case, surface tensile strength values of the concrete also range between min. 1.4 N/mm<sup>2</sup> up to max. 3.9 N/mm<sup>2</sup>. Only one test result is below 2.0 N/mm<sup>2</sup>. The high average value of 2.91 N/mm<sup>2</sup> proves that these reinforced concrete structures are very dense and that they feature an extremely durable surface structure. This demonstrates the enhanced resistance of concrete structures produced with Zemdrain<sup>®</sup> that are exposed to aggressive environments over a long time period.

The required minimum values according to ZTV-Ing. for a durable concrete surface of an average of  $\geq 1.5$  N/mm<sup>2</sup>

according to ZTV-Ing. were considerably exceeded.

An evaluation of the individual tensile strength test results for the internal face of the external wall produced with the formwork liner, in comparison to the spillway wall produced without the formwork liner, clearly also demonstrates that surface tensile strength without application of the formwork liner has dropped by approximately 30 %. This proves that the use of the Zemdrain<sup>®</sup> formwork liner considerably improves surface tensile strength for both structures.

Tests to measure the degree of abrasion of concrete surfaces after 56 freeze/thaw test cycles allowed for an additional assessment of the concrete surface quality (CIF test). These tests were carried out according to the regulations of the ZTV-Ing.

The test results referring to all concrete structures after 56 freeze/thaw cycles virtually do not show any decline of the relative dynamic E-modulus. Concrete structures are considered damaged as a result of freeze/thaw cycling as soon as the relative dynamic E-modulus after exposure falls below 75 %.

Test results show that concrete durability is also guaranteed in case of an alternating exposure of structures to freeze/thaw conditions and this applies for both the wastewater treatment plants in Offenburg-Griesheim and Bonn-Beuel.

All surfaces on which the Zemdrain<sup>®</sup> formwork liner had been used showed a considerably lower degree of abrasion than those produced without the formwork liner.

Pictures 4 and 5 show the surfaces of concrete cores extracted from the external wall below the maximum water level of the wastewater treatment plant Offenburg-Griesheim, which was cast using the Zemdrain<sup>®</sup> formwork liner on the internal face of the external wall only. Picture 4 shows the concrete surface prior to exposure to alternating freeze/thaw cycles and Picture 5 shows the concrete surface of the identical test specimen after exposure to alternating freeze/thaw cycles.



**Picture 4:** Test specimen U5, concrete surface prior to freeze/thaw cycle testing, concrete surface is cast using the formwork liner



**Picture 5:** Test specimen U5, concrete surface after completion of freeze/thaw cycle test concrete surface is cast using the formwork liner

The quantity of abraded material from the concrete surfaces produced with the formwork liner ranged between 200 g/m<sup>2</sup> up to approx. 500 g/m<sup>2</sup>. The limit value defined by the ZTV-Ing. amounts to 1500 g/m<sup>2</sup>.

Pictures 6 and 7 show the surfaces of concrete cores extracted from the permanently submerged spillway wall of the wastewater treatment plant Offenburg-Griesheim, which was cast without using the formwork liner, but the same concrete composition was used. Picture 6 shows the concrete surface prior to exposure to alternating freeze/thaw cycles and Picture 7 shows the concrete surface of the identical test specimen after exposure to alternating freeze/thaw cycles.

The quantity of abraded material from the concrete surfaces produced without the formwork liner ranged above the limit value of amounts up to 1500 g/m<sup>2</sup> defined by the ZTV-Ing.

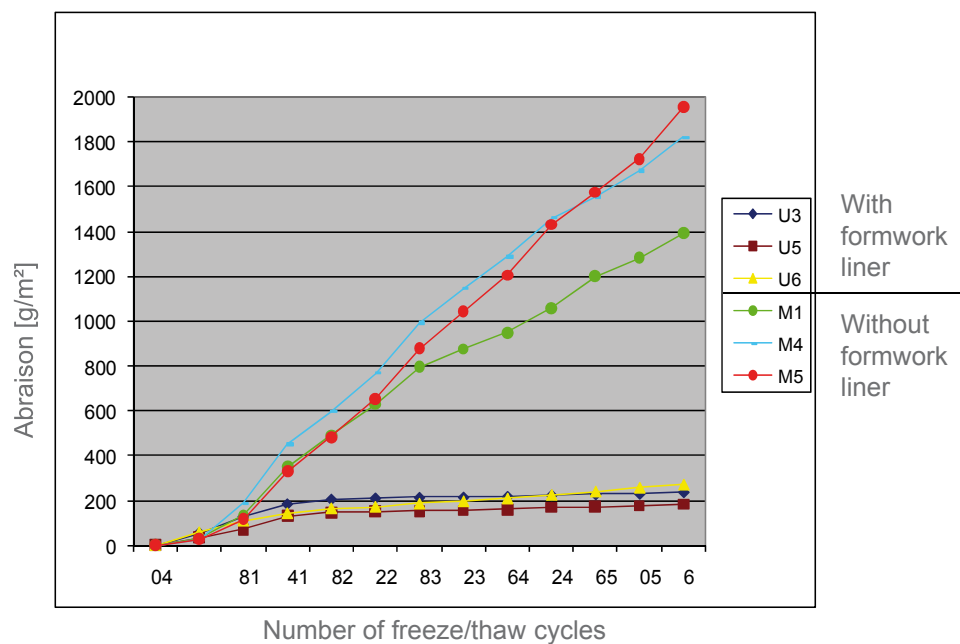
Table 2 shows graphically a comparison of three sets of samples from surfaces with and without the use of a formwork liner. Concrete surfaces produced without the formwork liner show a much more significant degree of abrasion. The degree of abrasion measured after an identical number of test cycles is on average 7.5 times higher than the value obtained at walls produced with the formwork liner (232 g/m<sup>2</sup> with Zemdrain® in comparison to 1722 g/m<sup>2</sup> without Zemdrain®). Test results obtained both, above and below the water level for Zemdrain® cast concrete show that for both wastewater treatment plants the quantities of abraded material are far below the limit value defined by the ZTV-Ing.



**Picture 6:** Test specimen M5, concrete surface prior to freeze/thaw cycle testing, concrete surface is cast without using the formwork liner



**Picture 7:** Test specimen M5, concrete surface after completion of freeze/thaw cycle test, concrete surface is cast without using the formwork liner



Picture 8: Abrasion in g/m² after freeze/thaw cycle testing

As concrete is placed against the formwork the energy imparted by the vibrator and the concrete pressure produced during the concreting process force excess mix water of up to max. 2.5 litres per m² from the concrete surface through the liner. This process does not only reduce the w/c value, but at the same time it optimizes concrete

aeration. Surface concrete thus becomes more compact and more dense.

Tests showed that concrete surfaces of structures both above and below the water level which had been produced with the Zemdrain® formwork liner, displayed a much denser surface structure than concrete structures that

had been produced with a conventional oiled formwork.

All tests on core specimens to assess surface quality and thus durability of reinforced concrete structures have produced evidence that the concrete quality of the outer concrete structure so produced is very durable.

## 6. Summery and Conclusion

In conformity with relevant regulations it is imperative to guarantee the durability of reinforced concrete structures exposed to aggressive environments, such as structures in wastewater treatment plants. The selection of the correct basic concrete materials is a decisive preliminary condition in order to guarantee the durability of all concrete structures exposed to attack. This preliminary condition is followed by the requirement for correct placing and compaction followed by an appropriate curing regime, in order to ensure a minimum w/c ratio especially at the surface of the concrete structure.

Although all of the parameters detailed above are usually complied with at the construction stage, it is common for subsequent damage to the concrete

surface to manifest itself within a few years. For the structures at the two sites investigated damage to the concrete was detected on the surfaces of the walls cast to these parameters after only a few years in service.

The present concrete inspection and evaluation of all test cores extracted from the two wastewater treatment plants after 10 years of operation evidently proves that the correct application of the Zemdrain® formwork liner considerably increases the durability and service life of reinforced concrete structures in aggressive environments. Damage to structures produced without the use of a formwork liner were immediately visible on site, whilst test cores produced using the formwork liner even after

56 freeze/thaw cycles showed only minimal abrasion (232g/m² with formwork liner in comparison to 1722g/m² without formwork liner).

These improvements considerably increase the potential service life of any reinforced concrete structure exposed to aggressive chemical and physical environments.

All individual test results and a much more detailed description of all assessed reinforced concrete structures is given in the experts report on reinforced concrete surfaces cast using Zemdrain® formwork liners in wastewater treatment plants after ten years of operation, issued by the FEhS - Institut für Baustoff-Forschung e. V., Duisburg, test report 2008/310.

## 7. The author

Dipl.-Ing. Klaus Lehmann who was born in 1955, has been managing director of the approved Testing, Supervision and Certification Authority of the federal state of North-Rhine-Westphalia FEhS – Institute for Construction Materials Research in Duisburg since 1990.

He is presently teaching construction engineering, specialism solid building at the University of Duisburg/Essen. Klaus Lehmann is member of various work committees and associations, member of the executive board and chairman of the quality control committee

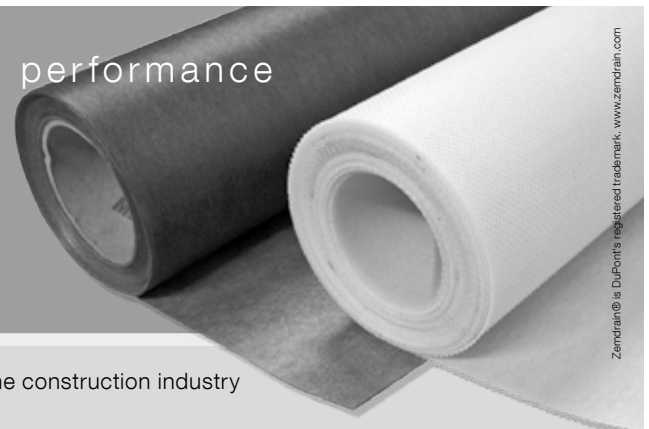
„Planning and maintenance of concrete structures“. Klaus Lehmann is author of numerous publications and scientific documentations and has therefore been a well-known personality in this specific field for many years.

## 8. Literature

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- Technical product documentation Zemdrain® issued by Max Frank GmbH & Co. KG, Leiblfing

## Zemdrain® | enhances concrete performance

Using Zemdrain® significantly improves the durability and quality of concrete surfaces ensuring an extended life for all structures in harsh environments, e.g. drinking water reservoirs, water, wastewater and sewerage treatment plants.



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