The current state of the art in construction material for sludge dry beds, clarifiers, vessels, trenches, and other structures in waste water treatment plants is concrete.

Polymer-based linings and coatings are applied to these concrete surfaces to increase their resistance to chemical attack, to obtain leak-proof structures, or to enhance their durability. However, the physical properties of concrete differ substantially from those of linings and coatings applied to them.

This article discusses the need for coatings and linings in waste water treatment facilities; how these systems differ from each other; concrete design and surface preparation requirements; and application of various types of coating and lining systems, including glass cloth-reinforced linings, glass mat-reinforced linings, and spray-applied coatings.

Need for Coatings and Linings in Waste Water Facilities

The chemical attack of waste water on concrete is traditionally attributed to hydrogen sulphide, which is generated by anaerobic sulphate-reducing microorganisms. While hydrogen sulphide can react with free lime in concrete to produce calcium sulphate, the most severe damage results from the production of sulphuric acid by aerobic sulphur-oxidising microorganisms.

The relationship of the pH value of the acid solution in a sulphuric acid attack, the cell count of microorganisms, and corrosivity is shown in Table 1.

Above a pH 3 value, the potential risk of attack can be avoided by various methods, such as use of a concrete based on sulphate-resisting cement or a calcareous aggregate, or by use of an additional thickness of sacrificial concrete. Below pH 3, it is generally necessary to provide additional...
where abrasion resistance is not absolutely necessary.

A wide range of coating and lining systems is available to protect concrete from exposure to moisture and chemical environments. These systems are typically based on acrylic, epoxy, furan, vinyl ester, polyester, and polyurethane resins. The characteristics and chemical resistance of these systems are shown in Tables 2 and 3.

Although furan-based resins show the best resistance against chemicals, their use in this field is limited, primarily because of the complexity of their installation procedure. Polyester and vinyl ester are the most versatile resins for chemical resistance, with epoxies not far behind. However, epoxies are the most compatible with concrete and far more tolerant of adverse conditions during installation. For this reason, epoxies are the most commonly used resins for lining and coating systems for concrete protection in waste water treatment facilities.

**Differences Between Linings and Coatings**

Linings are normally formulated from polymer resins with a proper balance of modifiers, fillers, and other active ingredients, and usually reinforced with glass cloth or glass mat. Linings are called monolithic when they adhere directly to a surface and form an integral protective barrier that is seamless and jointless. Unlike sheet linings or membranes, they do not rely on adhesives to bond them to the concrete substrate, and various characteristics distinguish them from protective coatings, as described below.

Lining reinforcements and modifiers are carefully selected for their ability to adjust the coefficient of expansion (a measure of the expansion of a material due to heat), which differs widely between concrete and unmodified resins. They must provide the flexibility to adhere to concrete in a wide range of service conditions as well as adhesion, physical stability, and permeation resistance.

Protective lining systems go beyond coatings by withstanding aggressive chemical environments in immersion service. The most important proof of this performance is ASTM C868, Standard Test Method for Chemical Resistance of Protective Linings, which measures a lining’s ability to withstand chemical attack while being subjected to a strong permeation force.

Coatings generally do not provide the resistance to the permeation driving force produced by elevated temperatures. They would be used for severe spillage or immersion conditions at ambient temperatures and in areas where abrasion resistance is not absolutely necessary.

High-build coatings filled with inert flakes such as mica, graphite, etc., normally range between 200 and 1,000 microns in thickness, whereas linings are applied in a thickness range of 2,000 to 5,000 microns.

Finally, linings generally are applied by trowel and roller, while coatings are applied by various techniques, including brush, roller, conventional spray, and airless spray.

**Design of Concrete**

Concrete constructions to be coated or lined should meet the requirements specified in DIN 1045, Concrete and Reinforced Concrete: Design and Construction (Beton und Stahlbeton: Bemessung und Ausführung).

Compressive strength, which is a measure of the compressive stress a material is capable of withstanding, should be at least 25 N/mm². However, this is only one measure of the quality of concrete. It is a measure of integrity, not surface

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**Table 1: Relation Between pH Value and Corrosivity**

<table>
<thead>
<tr>
<th>pH</th>
<th>Cell count</th>
<th>Corrosivity</th>
<th>Degradation of concrete surface per year</th>
<th>Refurbishment after years</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0-10²</td>
<td>low</td>
<td>powdering</td>
<td>&gt;80</td>
<td>HS cement, calcareous aggregate, sacrificial concrete</td>
</tr>
<tr>
<td>2</td>
<td>10²-10⁵</td>
<td>medium</td>
<td>&lt;0.5 mm</td>
<td>&gt;40</td>
<td>Corrosion protection with linings or coatings</td>
</tr>
<tr>
<td>3</td>
<td>10⁶-10⁷</td>
<td>high</td>
<td>&gt;0.5 mm</td>
<td>&gt;3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10⁸-10⁹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>10¹⁰-10¹¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HS=high strength
**Table 2: Chemical Resistance**

<table>
<thead>
<tr>
<th>Resin type</th>
<th>Bases/Alkalis</th>
<th>Organic acids</th>
<th>Inorganic acids</th>
<th>Aliphatic solvents</th>
<th>Aromatic solvents</th>
<th>Chlorinated organic solvents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>1</td>
<td>3-4</td>
<td>3-4</td>
<td>3-4</td>
<td>2-3</td>
<td>3-4</td>
</tr>
<tr>
<td>Polyester</td>
<td>3-4</td>
<td>3</td>
<td>1-2</td>
<td>2-3</td>
<td>3-4</td>
<td>3-4</td>
</tr>
<tr>
<td>Vinyl ester</td>
<td>2-3</td>
<td>2-3</td>
<td>1-2</td>
<td>2-3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Furan</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Polymethyl methacrylate</td>
<td>3</td>
<td>2-3</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>3-4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>3-4</td>
<td>4</td>
</tr>
</tbody>
</table>

1 = Resistant until maximum concentration  
2 = Limited resistance  
3 = Conditional resistance (temperature & concentration)  
4 = Not resistant

strength. Tensile strength of the concrete surface after preparation is the most important property for the performance of immersion coatings and linings. Tensile strength is the strength of a material subjected to tension and reflects the stress it is able to resist when force is applied.

Since lining performance depends largely on its bond to the substrate, the concrete must have high surface strength. To measure surface tensile strength, a machined pipe cap is glued to the surface and, after hardening, it is pulled off using a stress-measuring instrument. The force required to remove it should be at least 1.5 N/mm² for most applications. The results can be evaluated as shown in Table 4, which is based on BS 1881, Testing Concrete: Part 207, Recommendations for the Assessment of Concrete Strength by Near-to-Surface Tests, Method C (Pull-off).

If concrete has a high water content, its compressive strength is normally decreased. More importantly, a large amount of water-containing sand and cement may bleed to the surface, resulting in a weak, thin, brittle layer of cement and aggregate fines known as laitance.

When cement dries too rapidly, it develops low surface strength, which is a detriment to lining performance. However, it is not desirable to use a curing sealer, since it would have to be removed before priming. Therefore, proper curing is exceedingly important.

To obtain a proper surface finish, poured concrete should be float-finished and troweled at the correct intervals to produce a densified surface with minimum laitance. Only one pass with a trowel is needed. Additional trawelling or power trowelling may increase surface preparation costs without benefit.

Formed concrete is relatively uniform in quality and not subject to variations in curing as in surface-finished concrete slabs. Defects in formed concrete that affect performance of immersion linings and coatings are air pockets (bug holes), pinholes (indicating hidden air pockets), tie holes, form burrs, and honeycombs. These defects can increase the cost of application, since they must be filled with a proper material prior to the application of linings or coatings.

Correctly designed concrete structures should be placed on a bed of gravel or sand rather than directly on soil, particularly clay, to minimise the capillary flow of water from the soil through the concrete. A vapour barrier beneath the concrete structure is also desirable.

The maximum moisture in concrete should not exceed 3 percent, as measured by ASTM D4263, Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method. This test indicates the presence of moisture in concrete by taping a plastic sheet of 120 cm² to the surface to be coated or lined. The test should be conducted when the ambient conditions and surface temperature are within the established parameters for application of the specified lining or coating system. The plastic sheet remains on the substrate for at least 16 hours. Upon removal, the area is inspected for the presence (or absence) of moisture.

**Preparation of Concrete**

Concrete normally requires a 28-day cure prior to surface preparation and application of a lining or coating system. Surface preparation requirements will vary with the system selected. The properties and application requirements of the selected system should be determined before or during this process.
Surface preparation of concrete can involve repair of defects, surface cleaning, and mechanical preparation to clean and sometimes to roughen the surface. Some jobs may require all three kinds; others may require fewer. Generation of dust, slurries, or water during surface preparation may require containment and safe disposal.

**Repair of Defects**

Repair of protrusions, such as fins, can normally be accomplished with grinders or impact tools.

Spalls, cracks, and holes can be filled with portland cement-based materials, resin-based materials containing fillers, polymer-modified concrete, or shotcrete. Proper repair of cracks requires a V-shaped notch (i.e., wider at the surface) cut into the concrete along the crack to enable the repair material to obtain full strength and integrity.

Selection of repair material will depend on the size of the defect and the strength required of the substrate. Patching is normally done before other surface preparation such as blasting or high-pressure waterjetting.

(For more information, see the sidebar: “Cracks in Concrete Structures and Crack-Bridging Linings.”)

**Surface Cleaning**

Surface cleaning means removing contaminants such as dust or other loose foreign material and oil or grease that are on the surface but that have not penetrated the concrete. Wire brushing, broom cleaning, mopping, and vacuum cleaning can dislodge or remove foreign material.

Surface contamination by grease or oil requires some type of chemical cleaning such as scrubbing with detergents, caustic soda solutions, or other appropriate cleaning agents. The surface must be carefully flushed to remove both the chemical cleaner and the loose...

Table 3: Polymer Characteristics (Unreinforced) of Commercially Available Systems

<table>
<thead>
<tr>
<th>Properties after 7 days cure</th>
<th>Epoxy</th>
<th>Polyester</th>
<th>Vinyl ester</th>
<th>Furan</th>
<th>Polymethyl methacrylate</th>
<th>Polyurethane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength (N/mm²) DIN 53455</td>
<td>40-80</td>
<td>70-80</td>
<td>75-85</td>
<td>40</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Elongation at tear (%) DIN 53455</td>
<td>4-15</td>
<td>2.5-5</td>
<td>3-7</td>
<td>1.5-2</td>
<td>2</td>
<td>10-200</td>
</tr>
<tr>
<td>E-modulus (N/mm²) DIN 53457</td>
<td>1000-3500</td>
<td>3000-4000</td>
<td>3300-4000</td>
<td>5500-7000</td>
<td>2000</td>
<td>600-2700</td>
</tr>
<tr>
<td>Glass transition temperature (℃)</td>
<td>30-120</td>
<td>70-120</td>
<td>125-165</td>
<td>171</td>
<td>70</td>
<td>—</td>
</tr>
<tr>
<td>Density (g/cm³) Coefficient of expansion (10⁻⁶ 1/K) ASTM D696-90</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.22</td>
<td>1.2</td>
<td>1.1-1.3</td>
</tr>
<tr>
<td>Shrinkage (%) ASTM C531-85</td>
<td>0.5</td>
<td>2</td>
<td>2</td>
<td>0.5</td>
<td>1</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

DIN 53455, Testing of Plastics, Tensile Test
DIN 53457, Testing of Plastics, Determination of the Modulus of Elasticity by the Tensile Test, Compression Test, and Bending Test
ASTM D696-90, Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30 Degrees C and 30 Degrees C
ASTM C531-85, Standard Test Method for Linear Shrinkage and Coefficient of Thermal Expansion of Chemical-Resistant Mortars, Grouts, and Monolithic Surfacing, and Polymer Concretes

Table 4: Tensile Strength of Concrete

<table>
<thead>
<tr>
<th>Tensile</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1.0 N/mm²</td>
<td>poor</td>
</tr>
<tr>
<td>1.0 N/mm² – 1.3 N/mm²</td>
<td>marginal</td>
</tr>
<tr>
<td>1.3 N/mm² – 1.5 N/mm²</td>
<td>acceptable</td>
</tr>
<tr>
<td>Over 1.5 N/mm²</td>
<td>excellent</td>
</tr>
</tbody>
</table>

Fig. 1: Illustration of three coating systems commonly used in waste water treatment plants.
Cracks in Concrete Structures and Crack-Bridging Linings

Large concrete structures may crack before or after the lining or coating has been installed. Cracks can result from settling, but they are usually caused by relief or shrinkage stress. DIN 1045 requires the maximum width of cracks not to exceed 0.1 mm in chemically aggressive environments and 0.2 to 0.3 mm in other conditions. However, cracking within these parameters normally has no significant influence on the mechanical properties of the concrete structure; it mainly affects the chemical resistance. In a waste water environment, linings and coatings are generally very rigid because of the high crosslink density needed for optimum chemical resistance. If the concrete cracks, the lining or coating will also crack.

Generally, thin-film coatings will not offer crack-bridging capabilities. Therefore, development of corrosion-resistant linings that can bridge cracks in concrete substrates has great practical significance from both a technical and an economic point of view.

The basic concept behind a crack-bridging lining is to control the strain experienced by the chemical-resistant topcoat. This can be accomplished by using a very flexible base coat topped with a much higher modulus fibreglass-reinforced layer. The base coat serves to accept the movement caused by thermal expansion and contraction of the substrate, while the higher modulus reinforced layer spreads the shear forces from the base coat during any thermal cycling, thus isolating the topcoat.

However, efficiency considerations may limit the use of this method. (Acid etching as a method of cleaning and preparing a concrete surface generally is banned in Europe because of osmotic problems it produces.)

In addition to abrasive blasting and power tool cleaning, high- and ultra high-pressure waterjetting may be used outdoors to remove laitance, dirt, or water-soluble contaminants from concrete surfaces. This method is suitable for horizontal, vertical, and overhead applications. However, water alone will not etch or produce a surface profile.

Application

Prior to application, all people involved with a specified system should be fully aware of any safety considerations as well as the surface preparation and application requirements.

During application, special attention should be given to environmental conditions, which should meet the coating or lining manufacturer’s requirements for concrete moisture content, relative humidity, dew point, and minimum/maximum temperatures.

The most commonly used systems in waste water treatment plants are glass cloth-reinforced or glass mat-reinforced linings and spray-applied, flake-filled coatings. The three systems are illustrated in Figure 1.

The use of a conductive primer on concrete allows a spark test of the lining or coating after curing, in accordance with ASTM D4787, Standard Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates.

Typical lining or coating selec-
Spray-Applied, Flake-Filled Coatings

For spray application of flake-filled coating systems, airless spraying is preferred because it permits the flakes (e.g., mica, graphite, or glass) to be oriented parallel to the surface. Also, when airless spray is used, coatings do not require thinning before application. Different colours are used for each layer in order to ensure good coverage during application. At least two coats with a final dry film thickness of 200-1,000 microns, depending on the severity of the service, should be applied.

Glass Mat-Reinforced Linings

Glass mat reinforcement involves the use of chopped strand fibreglass mat in combination with a permanently flexible resin system. This design provides crack-bridging capability not provided by other linings or coatings and the tensile strength required for concrete protection.

Installation is similar to the method of installing a glass cloth-reinforced lining. Instead of glass cloth, however, a glass mat is applied onto the base coat and saturated with resin, which is applied by roller. A second layer of glass mat is then placed on the wet surface and saturated in the same manner. The mat should overlap at least 25 mm at all joints, but the laps of the two layers should not be in the same location. Before the second layer has hardened, a surface veil or tissue is laid on top and rolled. After the lining has hardened, bumps, loose fibres, etc., are sanded off. A resin topcoat is then applied as the final layer.

Glass Cloth-Reinforced Linings

In abrasive areas such as thickener tanks, clarifiers, and grit chambers, an appropriate lining is likely to combine a resin with two or more times its weight in filler and include glass cloth reinforcement. This system probably would consist of a 1.5 mm trowel-on base coat, a layer of woven glass reinforcement, a saturating layer of resin, and a finish coat with a different filler than the base coat. Applying the lining in a thin layer (1.5 mm) minimises total shrinkage stress of the lining system and allows the glass cloth reinforcement to adhere to the substrate. The glass cloth reinforcement further reduces shrinkage and strengthens the lining. Since it is practically impossible to obtain a void-free lining in one coat, a 1.5 mm topcoat covers any voids in the base coat and the reinforcement. The filler in the topcoat should provide abrasion and impact resistance.