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Corrosion in Concrete

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Abstract

Corrosion of steel occurs. Corrosion of reinforcement bars are complex but basically it is an electrochemical reaction similar to that of a simple battery. Detoriation of concrete is mainly due to corrosion of steel. The phenomenon corrosion in concrete is treated as “Cancer” in concrete. Initially the PH value of concrete is taken as more than 12.5 which is highly alkaline. However over passage of time the carbonation or ingress of chloride ions takes place and PH value starts decreasing. Slowly the alkanity around the steel bars is lost. So corrosion process takes place. This causes cracks and spalling of concrete. Most of RCC detoriation is due to corrosion of steel so, corrosion process must be discussed and explained elaborately. Steel embedded in hydrating cement paste rapidly forms a thin passivity layer of oxide and which causes strong adhesion to steel and protects steel from the reaction of water and oxygen. This state of steel is called as passivation. When low PH front reaches at the surface of reinforcement bars then the oxide film is reduced and corrosion takes place. So oxygen and moisture are mainly responsible for corrosion effect.

Different reasons for corrosion:

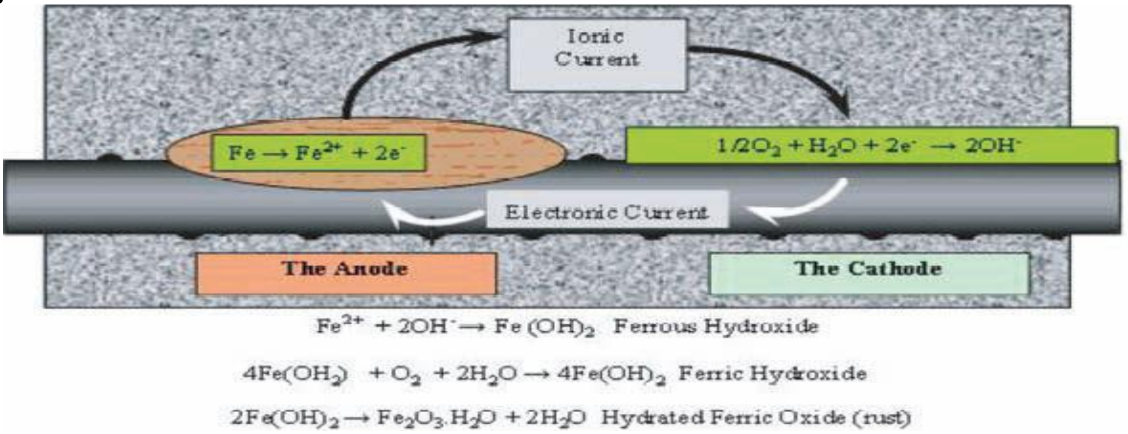
1. Due to low quality of concrete.
2. Less cover thickness.
3. Contamination of steel with salt, acid and minerals.
4. Effects of minerals and other environment conditions.
5. Porosity of concrete.
6. Due to high thermal stress.
7. Due to freezing and thawing effects.

Keywords: Corrosion, steel, concrete, detoriation, epoxy.

Introduction

In my past employer M/S: CBNL, Lagos, Nigeria, I have investigated the causes of corrosion and and its rememdy with necessary experiments. We can see in the following diagram: 01, the cathodic reaction requires water and oxygen. The initial anodic reaction does not require any reactants until the iron has become soluble ferrous ions that can then react with hydroxyl ions (the alkalinity in the concrete), and then with oxygen and water to create the solid rust whose volume increase will crack and spall the concrete. The fact that oxygen is not required at the anode is important because the exclusion of oxygen from anodic areas without stifling the cathodic reaction will lead to dissolution of the reinforcement rather than cracking and spalling of the concrete, i.e. the structure is weakened without there being evidence of deterioration. This can happen in local saturation conditions where the concrete is very wet and therefore conductive enough to allow good separation between anodes and cathodes. This process is known as differential aeration where the electrons are used to form H+ ions at the cathode that are free to react with chloride to form hydrochloric acid within, for example pits and crevices on the steel surface. Further oxygen starvation within the pit or crevice leads to enhanced degradation and rapid failure. The ingredients for corrosion are therefore: carbonation or sufficient chloride at reinforcement depth to de-passivate the steel oxygen to fuel the cathodic reaction and to create the expansive oxide water to fuel the cathodic reaction and to create the expansive oxide concrete of low enough resistivity to allow the electrochemical anode and cathode reactions to proceed.

Diagram: 01



Science of Corrosion

As per electrochemical corrosion cell following steps could found out.

1. Initiation: Chloride contamination and corrosion initiation. Starts with red in color.
2. Cracking: Cracking occurs when the corrosion-induced tensile stresses exceed the tensile strength of concrete. (Could be inclined or parallel to the surface.).
3. Fracture: When cracks are parallel to the surface.
4. Elimination: This is the last stage which accelerates the process and continuously concrete starts go away from drain wall or surface floor.

When it goes to Severe Stage

1. Carbonation and diffusion of chlorides are the initiation stage of deterioration level; which seems like normal concrete and repairing is not required.
2. Propagation or rapid corrosion when reaches at last stage of deterioration level; then repair becomes necessity.
3. But during that stage it could affect other structures like foundations, steels, etc. which becomes severe and unsafe.

How corrosion affected to C.B.N.L. (Back side factory)

1. This photo is collected from the back side of factory drain where corrosion is already started. This drain is interlinked to factory.
2. Due to this corrosion the existing boundary wall base is also affected.
3. The white color material floating is the concrete base of drain which is corroded and coming out like dust particles.
4. As this drain is linked to the factory and as due to continuous flow of concrete dust now the slope of drain became varying and which is causing water steady.
5. We could not able to get the inside drain situation of factory as it is covered with concrete floor.
6. So we would put this drain in Medium stage with respect of priority wise.

7. Some parts of loose concrete has been collected and presented in first photo.
8. Second photo will show the red colored corroded parts floating on water.
9. The wall became hollow from bottom end.

10. Drain floor is going out due to corrosion or acids coming from factory.
11. Water bubbles are caused due to the acidic reactions.

12. Corrosion is proceeding to inside of factory gradually through the bottom of drain.

13. Acid started depositing due to final slope difference.

Advantages and Disadvantages of different procedures to protect concrete from corrosion:
Rubber Sheet and Mats
Advantages

Rubber floors provide a resilient, ergonomic surface that eases the strain for personnel who must stand at workstations for long periods of time. Their surfaces are easily cleaned, and they provide very good water, chemical, and wear resistance for foot traffic. Rubber sheet floors are rather expensive to purchase and require a fair amount of skill to install properly. Rubber mats are relatively inexpensive to purchase and are easy to install.

Disadvantages

Rubber sheet floor seams tend to separate allowing water and chemicals to reach the concrete. Conventional cleaning and disinfection operations cannot reach these areas, so they become ideal places for bacteria to propagate. Microbes and fungi can also be harbored underneath rubber mats. Extra cleaning and sanitation steps must be taken to address areas covered by the mats. The mats can be trip or fall hazards at transitions. Rubber sheet floors and mats can be damaged by heavy abrasion. They are usually not suitable for equipment traffic ways. Bonded rubber floors are susceptible to delaminate resulting from MVT and ASR.

Brick, Tile and Stone
Advantages

These materials, when properly selected and installed, provide very long life under heavy use. They have good resistance to the chemicals commonly encountered in food plants, and they have very good thermal stability.

Disadvantages

The grout joints in these types of floors are always problematic. Thermal cycling causes expansion / contraction differentials between the flooring material and the grout joints. This results in the formation of cracks, which allows chemicals to penetrate the floor and eventually attack the setting bed below. Brick "growth" is the long term swelling of bricks caused by the absorption of moisture. This swelling can cause grout failures. Improperly placed expansion joints can exacerbate this problem. These cracks can challenge the plant's sanitation efforts, as they can also harbor bacteria. The sheer number of grout joints present in a typical installation makes this potential problem a significant concern. These types of flooring materials are susceptible to breakage under heavy impact conditions. Brick, tile, and stone floors are some of the most expensive to install, as they require qualified workers with highly specialized skill sets. Brick floors are relatively slow to install. This issue can prove difficult to manage given the typically very short timeframes available for repair and renovation work.

Polyurethane - Polyurea – Hybrid Coatings:
Advantages

100% solids polyurethanes, polyureas, and hybrids can provide seamless homogenous surfaces that are very resistant to mild acids, mild caustics, and water. They are fast setting and fast curing membranes (20 to 80 mils) that can handle heavy foot traffic and light to moderate equipment traffic.

Disadvantages

These systems do not tolerate damp substrates during installation. Their resistance to chlorine is suspect. They can become quite slippery when wet. Their impermeability makes them susceptible to (MVT) and (ASR) related delaminate. In most cases they are spray applied, which can result in atomized materials drifting through ventilation and air make-up systems or settling on unprotected food products and equipment. They are relatively expensive systems that usually require specialized equipment to apply. While there may be other applications for these systems within a food plant, their properties are not well suited for use on process area floors.

Epoxy Slurry and Mortar
Advantages

Many epoxy resins are available with a wide range of physical and chemical properties. 100% solids epoxy resins exhibit minimal shrinkage as they cure. This minimizes shear stress at the bond line, thereby contributing to very good adhesion of the resin to the substrate. Indeed, epoxy resins demonstrate tenacious adhesion to properly prepared substrata. They are hard, tough, and resistant to a wide range of chemicals. Heavy-duty epoxy surfaces are aggregate filled. Properly selected aggregate fillers significantly improve impact and abrasion resistance. These fillers can also provide thermal insulation properties at thickness, which improve the thermal cycling properties of the filled system as compared to the neat epoxy resin. The advent of 100% solids resin technology has resulted in very low odor, fast cure systems that can handle various aggregate loading rates. This allows for some flexibility in adjusting the handling characteristics of the systems in the field.

Disadvantages

Epoxy systems are relatively impermeable. This makes them subject to the effects of MVT and ASR. Epoxy systems are very rigid with relatively poor flexibility. The glass transition temperatures (Tg) of most epoxy resins are generally in the range of 1500 F (650 C) to 1600 F (710 C), which limits their use in hot environments, although there are some epoxy resins that can handle temperatures in excess of 4000 F (2040 C). Epoxy resins typically do not cure well in cool, damp conditions, which are common in meat processing plants. They can be difficult to recoat. Most epoxy resins do not perform well in long-term exposures to organic acids. Epoxies are also prone to delaminate from the substrate in areas subjected to severe thermal cycling. Care must be taken to ensure the resins and curing agents are combined at the proper ratios and then thoroughly mixed prior to application. Proper ambient conditions must also be maintained during the cure cycle.

Polyester / Vinyl Ester

Advantages

Polyester resins are relatively inexpensive. The most common resin types are orthophthalic and isophthalic. Orthophthalic polyesters are commonly used because they are more economical. Isophthalic polyesters provide better water resistance, but they are more expensive. Polyesters can be cured very quickly across a fairly broad temperature range, and they provide very good resistance to dilute acids, including organic acids. They are usually applied in multiple lifts, which helps to fill minor imperfections in the floor and provide an aesthetically pleasing finish. In food plants, polyester systems are often sealed with vinyl ester topcoats for improved water and chemical resistance, particularly to caustics. Vinyl ester resins are tougher and more resilient than polyester, which makes vinyl ester a better choice as a wear surface versus polyester. These systems allow some flexibility in catalyzation and acceleration to accommodate changing field conditions.

Disadvantages

Polyester and vinyl ester resin components are flammable and they emit very strong odors during installation and cure. These resins are typically dissolved in styrene, a very flammable material with a very pungent odor. Their cure reactions are initiated with organic peroxides, e.g. methyl ethyl ketone peroxide, which can be extremely hazardous, even explosive. Accelerators made from cobalt compounds are often used. Great care must be taken to ensure proper proportioning of the resin, catalyst, and accelerator components. Polyester and vinyl ester resins undergo significant shrinkage as they cure, which can lead to the development of considerable shear stress at the bond-line. They are also subject to delaminate resulting from severe thermal cycling. Aggregate fillers can alleviate some of the shrinkage stresses and act as insulation to improve the thermal expansion/contraction properties of the neat resin. Polyester and vinyl ester resins are also prone to water degradation due to the presence of hydrolysable ester groups in their molecular structures (3). This results in a significant reduction of the inter-laminar shear strength of the resin when these resins are subjected water exposure for extended periods. Vinyl ester resins provide better resistance to water degradation, but neither polyester or vinyl ester perform as well as epoxy in this regard (4). Polyester and vinyl ester systems are also susceptible to delaminate from excessive MVT and ASR exposures.

Methylmethacrylate (MMA)

Advantages

MMA provides very fast cure to service times, even at very low temperatures. It has a low shrinkage rate, good chemical resistance, and low water absorption properties. MMA exhibits very good compressive, tensile, flexural, and shear strength, and it provides good acid resistance.

Disadvantages

MMA is highly flammable in its uncured state. It emits very strong and pungent odors during installation and cure, although these systems typically cure in one to two hours. MMA will not tolerate damp substrates, and any aggregate fillers must be thoroughly dry before incorporation into the resin. High relative humidity can adversely affect the cure of MMA resins. MMA is subject to delaminate from severe thermal cycling, excessive MVT, or ASR exposures. MMA is an expensive resin system compared to other resinous materials.

Cementetious Urethane

Advantages

Cementitious urethanes combine waterborne urethane resins with Portland cement, lime, and graded aggregates to provide fast cure, moisture tolerant systems with no strong odors or flammability hazards. They cure quickly in the cool and moist conditions typical of meat processing plants. These systems provide very good chemical resistance, particularly to organic acids and common cleaning and sanitation chemicals. They provide excellent impact and abrasion resistance. There is very little shrinkage during cure, and their adhesion to prepared concrete is tenacious. Because their composition is very similar to that of concrete, their coefficient of thermal expansion is very close to that of concrete. Thus, at comparable thickness, cementitious urethanes provide the best resistance to delaminate from thermal cycling versus all other resinous systems. Their permeability to water *vapor* helps them to provide the best resistance to MVT and ASR related failures (4). Cementitious urethane systems can be applied to green concrete as soon as the concrete can be shot-blasted. These systems can be installed to considerable thickness in one step, thereby shortening the installation time versus all other resinous systems. No specialized equipment or installation methods are required to place the material. Optional broadcast media and seal coats can be applied to improve aesthetic and slip resistance properties and to meet specific chemical resistance requirements. Soundly adhered cementitious urethanes can be recoated with minimal surface preparation. Cementitious urethanes work best in temperatures from 450 F to 850 F and relative humidity below 85%. They can be installed at temperatures as low as 350 F and relative humidity as high as 99%.

Disadvantages

The working time of a cementitious urethane is very short, so projects must be thoughtfully planned and executed by skilled installers. Cementitious urethanes generally are not pretty floors. The one pass installation method leaves little opportunity to

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address and repair installation defects, so skilled labor is required. Unsealed cementitious urethanes can shed their broadcast aggregates more quickly than other resinous systems. However, aggregate retention can be improved through the use of optional seal coats. The recoat ability of the system allows for the redressing of the non-slip profile with select resin systems and broadcast media with little surface preparation and minimal interruptions to plant operations.

Stainless Steel Based Drain

Advantages

Best option in world wide. Manufactured from Stainless Steel to ensure acid corrosion and stain resistance.

1. Ensures odor-free operation.
2. Smooth surfaces for easy cleaning, minimum dirt collection and high flow rates.
3. A water proof material.
4. Easy to dismantle for cleaning.
5. A corrosion free material.
6. Low maintenance and high durable material.
7. Flow Rate: 4.5 l/sec which is much higher than others.
8. Worldwide accepted with high material value.
9. Typical uses: General Food Processing, Wine, Beverage, Dairy, Packaging etc. industries.

Disadvantages

Highly expensive.

Comparisons on Financial and Technical Aspects

Comparisons for all types of Possible Applications										
Flooring Type / Typical Properties	Rubber Flooring	Brick / Tile / Stone	Polyurethane / Polyurea / Hybrid	Epoxy Coating	Epoxy Slurry	Epoxy Mortar	Aggregate Filled Polyester / Vinyl Ester	MMA	Urethane Cement Slurry / Mortar	Stain Less Steel
HMIS Flammability Code	0	0	1	1	1	1	3	3	1	NIL
Odor	Slight	Slight	Moderate	Slight	Slight	Slight	Strong	Strong	Slight	Nil
Speed of Installation	Slow	Very Slow	Fast	Fast	Fast	Slow	Fast	Fast	Fast	Slow
Return to Service	12- 24 Hrs	2-7 Days	8-24 Hrs	8-24 Hrs	6-24 Hrs	6-24 Hrs	6-8 Hrs	2-4 Hrs	4-8 Hrs	5-6 Hrs
Surface Cleanability	Very Good	Good	Very Good	Good	Good	Good	Good	Good	Good	Very Good
Abrasion Resistance	Fair	Very Good	Good	Fair	Good	Very Good	Very Good	Very Good	Very Good	Very Good
Impact Resistance	Very Good	Very Good	Very Good	Poor	Good	Very Good	Very Good	Very Good	Very Good	Very Good
Compressive Strength	Poor	Excellent	Fair	Fair	Good	Very Good	Very Good	Very Good	Very Good	Very Good
Permeability	Very Low	Very Low	Very Low	Low	Low	Low	Very Low	Very Low	High	High
Installed Cost	N1200 -N1500 sq ft	N3000 -N4500 sq ft	N900- N1800 sq ft	N225 -N450 sq ft	N450-N900 sq ft	N450-N1200 sq ft	N450-N1200 sq ft	N1650-N2250 sq ft	N750-N1500 sq ft	N150,000
Availability	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Yes
C.B.N.L. Recommendation	No	No	No	No	No	Yes	No	No	No	Yes

Conclusion and final Recommendation

1. To start a repairing project this will cover all the hollows with fiber concrete and cracks with mortars. This will be temporary solution to avoid present situation.
2. Next drain reconstruction with epoxy / Stainless steel project to be done. As stainless steel is highly expensive so we could work with epoxy-mortar.
3. Next project could be Sewage Treatment Plant.
4. As corrosion is a common problem in all over the world; still monthly inspection and repairing could help us to assess the future problems.

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