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Challenging carbonation and corrosion of concrete: enhance durability, safety and sustainability.

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TECH-DRY INDIA

Tech Dry has been a thought leader in the Indian waterproofing and building construction market since 1992. Through a collaboration with Tech Dry Australia, we brought into the Indian market technology that was scientific, new-age and environmentally friendly. Founded and led by Dr. S.P.Bhatnagar, a scientist of the highest caliber and repute, Tech Dry India has remained true to it's mission: to scientifically understand problems of waterproofing and develop innovative yet practical solutions for our customers that were non-hazardous to either the user or the environment. Dr. Bhatnagar was devoted to not just undertsnading the science, but also sharing that knowledge with the larger construction industry. Impressing upon it the role of environmentally responsible approaches needed, and that could be taken, for truly sustainable structures.

Over the last 20 years, we have maintained our close customer interaction and strong focus on R&D to use our scientific and technical knowledge and bring innovative, 4th generation products to the Indian Market. With and extensive product line-up, we offer eco-friendly solutions in admixtures, crystallization , repellency impregnants, polymer modified mortars, elastomeric coatings, grouting and more. One important thing to understand is how waterproofing chemicals can help protect reinforced concrete from the negative effects of carbonation and corrosion of reinforcement. Products discussed here have a direct ability to enhance the durability, safety and sustainability of structures.

Concrete is the most widely used construction material and a lot of scientific knowledge regardings it's properties are known. Reinforced concrete as a building material has revolutionarised the construction industry, allowing it to build bigger, stronger and sometimes truly amazing structures. As our scientific understanding of concrete has grown, we understand better why problems with concrete can occur. The problems of stone decay and concrete deterioration and corrosion share several similarities: ingress of water-borne reagents by capillary action and the penetration of gaseous influences. **Protekta anti-carbonation and anti-corrosion** products have given very impressive results in accelerated tests for both water and salt penetration, significantly reducing damage caused by both. Degeneration of reinforcement needs to be addressed so that we can slow down if not stop it's progression. Without this, buildings will not be durable or safe. Depending on the chemistry of the environment, corrosion can set-in as early as 3 months of exposure to damaging environment.

Concrete as an Environment

Chemically speaking, the environment provided by good quality concrete to steel reinforcement is one of high alkalinity (pH > 12) due to the presence of the hydroxides of sodium, potassium and calcium that are produced during the hydration reaction when concrete is mixed with water. Under ideal conditions, reinforcement embedded in concrete will not corrode as the alkaline pH of concrete provides a protective environment for the steel reinforcement, wherein a thin film of passivating iron oxide forms on the surface of the steel (Hausmann, 1965)[1]. The bulk of surrounding concrete acts as a physical barrier to many of the steel's aggressors. In such an environment steel is passive and any small breaks in its protective oxide film are soon repaired. However, if the alkalinity of its surroundings are reduced, which occurs through neutralisation then severe corrosion of reinforcement can, and does occur. Corrosion is an irreversible process. Remedial measures cannot help restore the section. It can only help in delaying the process. So prevention for outweighs trying to cure.

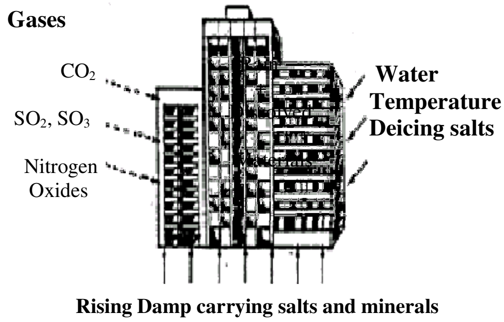
Despite best efforts, even correctly made and designed concrete is prone to developing cracks, and is chemically predisposed to absorbing water, which carries along with it atmospheric pollutants into the concrete. Early work in understanding this came from West Germany on the weathering of natural stones, by Dr. J. Hirschwald, who in 1908 published the book “The Testing of Natural Stones and Their Weather Resistance”. In this book Hirschwald stated that the problem was that by intrinsic contact with the stone surface, water enables carbon dioxide and oxygen to enter the inner parts of the stone by capillary action. This statement may be extended to state that regressive reagents may enter as a gas or in solution.

Key environmental factors like atmospheric carbon dioxide (dissolved in water this forms carbonic acid), other sulphuric or nitric acids (acid rain) or depassivating anions such as chloride are able to reach the steel. These are aided by other factors which may influence either the initiation or rate of reinforcement corrosion including cracks in concrete, including temperature, moisture, oxygen and inadequate concrete quality or cover. This in turn can result in rusting of reinforcement and spalling of the cover due to the larger volume that iron oxide occupies by comparison to the original reinforcement iron.

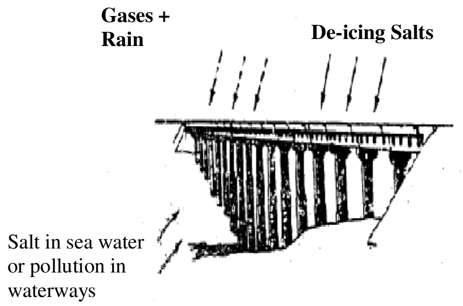
Factors influencing corrosion of reinforced concrete:

- Chloride ions
- Carbonation
- Change in the rebar environment (impinging cracks)
- Sulphate attack of concrete
- Salt recrystallisation (exfoliation)
- Soft water/acid attack of concrete
- Alkali Aggregate Reaction (AAR)
- Thermal incompatibility of concrete components (TICC)
- Shrinkage
- Frost Damage

Deterioration of concrete structures due to corrosion of the embedded reinforcement is a worldwide problem. Structures exposed to marine environments or deicing salts are particularly at risk. However, as environmental pollution has increased as has carbon dioxide emission levels, most concrete and natural stone structures are at risk. As steel reinforcement cannot be inspected visually, corrosion often remains undetected until extensive cracking or spalling has occurred. This damage can reduce the service life of the structure and more importantly, can create a safety hazard. The corrosion of reinforcements has resulted to be one of the most frequent causes of their premature failures, which can set in, as early as three months depending on the surroundings. The widespread deterioration of structures emphasizes the vulnerability of concrete protection as reinforced or prestressed concrete interacts with severe service environments.



Deteriorating Environmental Influences on Building Structure



Deteriorating Environmental influences on Bridge Structure

Legend to picture: Carbonation is the damage caused by carbondioxide which is a process in which carbon dioxide from the atmosphere diffuses through the porous concrete and neutralizes the alkalinity of concrete. The carbonation process will reduce the pH to approximately 8 or 9 in which the oxide film is no longer stable. With adequate supply of oxygen and moisture, corrosion will start. The penetration of concrete structures by carbonation is a slow process, the rate of penetration primarily depends on the porosity and permeability of the concrete. The process of carbonation of concrete may be considered to take place in stages. Initially, CO_2 diffusion into the pores takes place, followed by dissolution in the pore solution. Reaction with the very soluble alkali metal hydroxide probably takes places first, reducing the pH and allowing more $Ca(OH)_2$ into the solution. The reaction of $Ca(OH)_2$ with CO_2 takes place by first forming $Ca(HCO_3)_2$ and finally $CaCO_3$, the product precipitates on the walls and in crevices of the pores. This reduction in pH also leads to the eventual breakdown of the other hydration products, such as the aluminates, C-S-H gel and sulfoaluminates. Generally, it is found that good compaction and curing cause larger improvements in concrete permeability and resistance to carbonation than minor alternations in mix design.

Role of protective coatings in preventing or reducing corrosion

When unprotected external reinforced concrete is placed in the environment, deterioration begins immediately. There are many methods and certainly a multitude of products available to protect concrete. The objective is to reduce corrosion of metals in concrete and related problems, as well as improve other characteristics of the concrete matrix that cause various types of deterioration. This is generally accomplished by limiting the intrusion of moisture, chlorides, carbon dioxide, and other contaminants into the concrete substrate by surface treatments or by electrochemical principles.

Surface sealers and high-build coatings

For years, surface treatments have been the most common method of protection. The objective of a surface treatment is to limit corrosion by minimizing free water in the capillaries of the concrete. Surface sealers however, have not been very successful as they block the pores of the concrete and prevent natural breathing and tend to last for a significantly shorter time. Any damage to the surface including any debonding makes the underlying structure immediately succeptible to water damage.

It has been suggested that elastomerics may provide good anticarbonation resistance, which could be beneficial where concrete coverage over reinforcing is insufficient. Included in this group are: epoxies, polyurethanes, methyl methacrylates, moisture-cured urethanes, acrylic resins, certain paints (oil-based and latex) and silicone water-based elastomers. Although most elastomers will not bridge moving cracks, they may be effective in bridging nonmoving cracks. However, there are some elastomeric coatings that will bridge small moving cracks if properly detailed. Selection of an individual product may depend on its ability to breathe (or in some cases to act as a vapor barrier), as well as to provide sufficient resistance to water penetration. Many of these products are affected by UV and will wear under surface abrasion.

Epoxy Coated Reinforcing Steel (ECR) is one of the common materials used however concerns regarding it's adhesion ratings have raised concerns about the long-term performance of ECR in the concrete environment. In a study in Virginia, time from the initiation of corrosion to cracking and delamination in bare reinforcing steel is about 5 years. Their study indicated that the epoxy coating debonded from the reinforcing steel in as little as 4 years. Thus, it is apparent that the epoxy coating will be completely or partially debonded from the steel before the chloride ions arrive at the bar depth. Coating techniques always pose a problem of debonding and sometimes the debonding was not caused by the presence of chloride ions on the steel surface or excessive coating damage, instead, the loss of adhesion was related to water penetrating the coating and accumulating at the metal/coating interface, causing peeling stresses exceeding the adhesive bond strength and subsequent oxidation of the steel surface.

Large number of **membranes** have been tried, they have not been found suitable and degeneration, debonding is very common in these cases.   It is also found that some of the membranes are not compatible with concrete creating more problems than solutions.

Impregnants

In view of the difficulties incurred by some of the coating techniques, impregnation is carried out by spraying concrete surfaces with hydrophobic pore-lining mateiral, which reacts with the silicates and moisture present. This produces a water-repellent but vapour-permeable layer that inhibits the ingress of water and chloride ions but does not restrict breathability. Penetrating sealers include products with silicates, silicones, siloxanes and silanes. All of these interact with concrete and while silicates act mostly by partial filling of capillaries and pores reducing permeability, the silicones siloxanes and silanes all interact with concrete to produce the same end products, hydrophobic silica gel. The important distinction between these is the size of the molecules. The largest being silicones and the smallest silanes. The small size of silanes gives them the advantage of much deeper penetration but is offset with their high volatility which results in the easy loss of active material. When silanes are delivered to the surface in solvents that are also volatile the loss is further amplified. Silanes have been used for impregnation of concrete, but they are expensive and inefficient. Solvent-based impregnants also need critical surface condition of concrete to be effective.

Our mission at Tech Dry India, has been to remain solvent-free and develop water-based, non toxic solutions. The requirements of good sealers are that they are easy to apply, become integral to the concrete, curing time is as short as possible, must allow concrete to breathe, there should be no surface appearance change to concrete once it has dried. They should make the concrete resistant to not only water and water-borne pollutants but also to gasoline, diesel, and UV light. Two of our anti-carbonation and anti-corrosion products that offer all this will be highlighted here. Carbon dioxide and carbonation can be specifically excluded by the practice of treatment with an anti-carbonation impregnant. This then stops carbonation of the concrete so the concrete remains alkaline enough around the steel to keep the steel protected from corrosion.

PROTEKTA SILANE CREAM

An excellent product created by us **Protekta Silane Cream**, a 4^{th} generation product that overcomes the problems associated with liquid silanes. Protekta Silane Cream is an alkytrialkoxy silane and silicone ester based formulation that is not only water-based and environmentally friendly it is a non-drip, thixotropic cream that is stable over a long period of time. The low molecular weight, low volatility and cream consistency of **Protekta Silane Cream** ensure deep penetration and high quality water repellency in even the most dense concrete. Once the product has been applied to the concrete surface, it penetrates into the substrate and polymerizes forming a permanent hydrophobic layer, which resists water, chloride ion and other pollutants. It can be applied to any surface including overhead, vertical and horizontal without run off. The silane gel remains on the surface for up to 60 minutes ensuring deep and even penetration into the concrete. The high penetration depths achieved are due to the low volatility of the silane gel, combined with the long and uniform contact time with the surface. When water comes in contact with the treated surface, it simply rolls off.

USES

- Penetrates deeply into dense concrete
- Reduces application costs, only a single application is required
- Simplified application on overhead and vertical surfaces due to its thixotropic properties
- The product does not splash or run off uncontrollably onto the applicator
- No pollution of waterways and atmosphere due to no run off or evaporation
- The quality of application can be easily monitored by measuring the wet film thickness
- Reacts chemically with the concrete to form integral hydrophobic salt-resistant layers

- Protekta Silane Cream, which reduces water absorption over 94% and the chloride ion absorption rate is reduced by over 96%

PERFORMANCE

Depth of penetration: Protekta Silane cream penetrates evenly and deeply into high quality concrete. A single application of 200ml/mt^2 can penetrate up to 12mm into 20 mPa and 4-6mm in 50mPa concrete.

Water and chloride ion exclusion: Protekta Silane cream significantly reduces the water and chloride ion absorption of the treated concrete. Water absorption rate of Protekta Silane cream treated concrete is reduced by over 94% comparing to that of untreated concrete. The chloride ion absorption rate is reduced by over 96%.

Protekta Micro Emulsion

Another advanced waterproofing solution that can significantly reduce carbonation and corrosion of concrete and protects other natural stones from pollutant and water attack, is **Protekta Micro Emulsion**. This is a very unique formulation wherein a stable emulsion is created that allows for easy spray application to most surfaces using a low-pressure pump. The extremely small particle size permits the product to penetrate deeply and evenly into the surface, creating a permanent hydrophobic barrier. The treated surface remains unchanged and when water comes in contact with it, it beads and flows off. It has been found to reduce the relative absorption of water by upto 95%. The product is designed to penetrate to a depth of just a few millimetres and render the substrate water repellent. This water repellent zone dramatically reduces the absorption of water and water borne salts, while still allowing the free passage of water vapour.

OUTSTANDING FEATURES

- Easy application, no volatile hydrocarbons emitted during use
- Not a surface coating and therefore no peel or blister
- Becomes permanently chemically bound to surface
- Excellent surface beading effect
- Does not change the original surface appearance
- UV and alkali stable formulation
- Reduce water and chloride ion ingress by up to 95%
- Water-based product easy to use and easy to clean equipment after use

In a recent independent accelerated testing for penetration of chloride and water through concrete, it was determined to delay the onset of corrosion by 4 times than that of untreated concrete[2]. Both products were tested on concrete with a compressive strength of 29MPa after 28 days of curing and 7 days of drying. In the rapid chloride penetration tests, Protekta Silane cream was classified as per ASTM C1202 as having very low chloride ion permeability while Microemulsion was a moderate chloride ion permeability as compared to untreated concrete that had high chloride ion permeability. Untreated concrete began corroding in 21 days whereas the treated concrete delayed the cracking of the concrete by 4 times.

EXCLUSION OF THE FACTORS OF CORROSION FROM CONCRETE

As we have shown, it is possible using the science of building protection to effectively exclude water, chloride ion and carbon dioxide from new or old concrete so that deterioration does not proceed. This allows the durability and sustainability of the product to be maximized, offers long-term cost savings, is applicator friendly, does not pollute the environment and keeps the buildings we live in, work in and relax in, free from noxious harmful chemicals that not only hurt our environment but also our own health and safety.

References

1. Hausmann, D.A. (1964). "Electrochemical Behavior of Steel in Concrete," Journal of the ACI, (February 1964), American Concrete Institute, Detroit, MI, 171-187.
2. Tested for ASTM C1210-10, the chloride permeability is found to be very low. It delays time-to corrosion by up to four times when compared to control untreated concrete. (Tested at Central Electrochemical Research Institute (CECRI), Karaikudi, TN).