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Protection of Bio-Deteriorated Reinforced Concrete Using Concrete Sealers

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Abstract

Concrete, a most durable building material is mainly composed of water, aggregate and cement. It provides superior fire resistance compared with wooden construction and gains strength over time. Structures made of concrete can have a long service life. Reinforced concrete (RC) is a composite material in which concrete's relatively low tensile strength and ductility are counteracted by the inclusion of reinforcement having higher tensile strength and/or ductility. The reinforcement is usually, though not necessarily, steel reinforcing bars (rebar) and is usually embedded passively in the concrete before the concrete sets. Reinforcing schemes are generally designed to resist tensile stresses in particular regions of the concrete that might cause unacceptable cracking and/or structural failure. Concrete can be damaged by many processes, such as the expansion of corrosion products of the steel reinforcement bars, freezing of trapped water, fire or radiant heat, aggregate expansion, sea water effects, bacterial corrosion, leaching, erosion by fast-flowing water, physical damage and chemical damage. Many building structures undergo bio-deterioration when exposed to contact with soil, water and sewage as well as food, agricultural products and waste materials. Concrete sealers are applied to concrete to protect it from surface damage, corrosion, and staining. They either block the pores in the concrete to reduce absorption of water and salts or form an impermeable layer which prevents such materials from passing. Sealers are one of the most problematic and misunderstood aspects of concrete countertops. There is no review literature available about protection of reinforced concrete using concrete sealers. The present review includes reinforced concrete, hydration chemistry of portland cement, bio-deterioration of concrete and various types of concrete sealers for protection of reinforced concrete structures.

Keywords

Reinforced Concrete, Cement Hydration, Bio-Deterioration, Concrete Sealers

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1. Introduction

Concrete is a strong and cheap construction material and its application is rapidly increasing worldwide. However, they can get destroyed for a variety of reasons including the material limitations, design gaps and construction practices, as well as exposure conditions [1]. It is used more than any other manmade material in the world [2]. As of 2006, about 7.5 billion cubic meters of concrete are made each year, more than one cubic meter for every person on Earth [3]. Often, additives and reinforcements (such as rebar) are included in the mixture to achieve the desired physical properties of the finished material. When these ingredients are mixed together, they form a fluid mass that is easily molded into shape. Over time, the cement forms a hard matrix which binds the rest of the ingredients together into a durable stone-like material with many uses [4]. Old concrete is chemically stable and its porosity fully developed. The typical age of concrete depends on average annual temperature. All cement hydration chemical reactions go faster in warmer weather, the rate doubling with approximate every eighteen Fahrenheit degree

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increase. The present review includes reinforced concrete, hydration of portland cement, bio-deterioration of concrete and various types of concrete sealers for protection of reinforced concrete from deterioration.

2. Reinforced Concrete

Reinforced concrete is one of the most widely used modern building materials. Since concrete is a brittle material and is strong in compression. It is weak in tension, so steel is used inside concrete for strengthening and reinforcing the tensile strength of concrete. The steel must have appropriate deformations to provide strong bonds and interlocking of both materials. When completely surrounded by the hardened concrete mass it forms an integral part of the two materials, known as "Reinforced Concrete". It is currently the most common material used for the construction of the load bearing elements of structures. The rapid deterioration of concrete structures due to reinforcement corrosion has become a growing problem in recent years, effective to all kind of constructions, especially those located near to marine areas [5]. Cracks are forming in reinforced concrete elements due to bending, shear, torsion, tension or imposed deformations. Cracks worsen the durability and adequate perform of the structures and are a natural result of concrete low tensile strength [6].

Advantages of reinforced concrete

Reinforced concrete has greater compressive strength as compared to most other materials used for construction besides good in tension. It has better resistance to fire than steel and capable of resisting fire for a longer time. It has long service life with low maintenance cost. In some types of structures, such as dams, piers and footings, it is the most economical structural material. It can be cast to take the shape required, making it widely used in pre-cast structural components. Yield strength of steel is about 15 times the compressive strength of structural concrete and well over 100 times its tensile strength. Less skilled labor is required for erection of structures as compared to other materials such as structural steel.

3. Hydration of Portland Cement

Cement will remain the key material to satisfy global housing and modern infrastructure needs. As a consequence, the cement industry worldwide is facing growing challenges in conserving material and energy resources, as well as reducing its CO_2 emissions. According to the International Energy Agency, the main levers for cement producers are the increase in energy efficiency and the use of alternative materials, be it as fuel or raw materials. Cement production has undergone a tremendous development from its beginnings some 2000 years ago. While the use of cement in concrete has a very long history, the industrial production of cements started in the middle of the 19th century, first with shaft kilns which were later on replaced by rotary kilns as standard equipment worldwide. Today's annual global cement production has reached 2.8 billion tonnes, and is expected to increase to some 4 billion tonnes per year [7]. Several detailed reviews have been written about the mechanisms that are thought to govern the kinetics of hydration [8–9]. Portland cement consists of five major compounds and a few minor compounds. The composition of a typical portland cement is listed by weight percentage in Table-1.

Table 1. Composition of portland cement with chemical composition and weight percent [10-11].

Cement Compound	Weight Percentage	Chemical Formula
Tricalcium silicate	50 %	Ca_3SiO_5 or $3CaO{\cdot}SiO_2$
Dicalcium silicate	25 %	Ca_2SiO_4 or $2CaO{\cdot}SiO_2$
Tricalcium aluminate	10 %	$Ca_3Al_2O_6$ or $3CaO{\cdot}Al_2O_3$
Tetracalcium aluminoferrite	10 %	$Ca_4Al_2Fe_2O_{10}$ or $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$
Gypsum	5 %	$CaSO_4{\cdot}2H_2O$

When water is added to cement, each of the compounds undergoes hydration and contributes to the final concrete product. Only the calcium silicates contribute to strength. Tricalcium silicate is responsible for most of the early strength (first 7 days). Dicalcium silicate, which reacts more slowly, contributes only to the strength at later times.

$$2\ Ca_3SiO_5 + 7\ H_2O \text{ ---> } 3\ CaO{\cdot}2SiO_2{\cdot}4H_2O + 3\ Ca(OH)_2 + 173.6\text{kJ}$$

Upon the addition of water, tricalcium silicate rapidly reacts to release calcium ions, hydroxide ions, and a large amount of heat. The pH quickly raises to over 12 because of the release of alkaline hydroxide (OH^-) ions. This initial hydrolysis slows down quickly after it starts resulting in a decrease in heat evolved. Dicalcium silicate also affects the strength of concrete through its hydration. Dicalcium silicate reacts with water in a similar manner compared to tricalcium silicate, but much more slowly. The heat released is less than that by the hydration of tricalcium silicate because the dicalcium silicate is much less reactive. The products from the hydration of dicalcium silicate are the same as those for tricalcium silicate.

$$2\ Ca_2SiO_4 + 5\ H_2O \text{---> } 3\ CaO{\cdot}2SiO_2{\cdot}4H_2O + Ca(OH)_2 + 58.6\text{ kJ}$$

The other major components of portland cement, tricalcium aluminate and tetracalcium aluminoferrite also react with water. Their hydration chemistry is more complicated as they involve reactions with the gypsum as well. In general, the rates of hydration during the first few days ranked from fastest to slowest are:

Tricalcium aluminate > Tricalcium silicate > Tetracalcium aluminoferrite > Dicalcium silicate

Table 2. Chemicals that promote deterioration of concrete [16].

Rapid deterioration of concrete	Moderate deterioration of concrete	
Aluminum chloride	Aluminum sulfate	Mustard oil
Calcium bisulfite	Ammonium bisulfate	Perchloric acid, 10%
Hydrochloric acid	Ammonium nitrate	Potassium dichromate
Hydrofluoric acid	Ammonium sulfate	Potassium hydroxide (>25%)
Nitric acid	Ammonium sulfide	Rapeseed oil
Sulfuric acid, 10-80 percent	Ammonium sulfite	Slaughter house waste
Sulfurous acid	Ammonium superphosphate	Sodium bisulfate
	Ammonium thiosulfate	Sodium bisulfite
	Castor oil	Sodium hydroxide (>20%)
	Cocoa bean oil	Sulfite liquor
	Cocoa butter	Sulfuric acid, 80% oleum
	Coconut oil	Tanning liquor (if acid)
	Cottonseed oil	Zinc refining solutions

4. Bio-Deterioration of Concrete

Many architectural and other buildings structures undergo bio-deterioration in their service life. Bio-deterioration refers to undesirable changes in a material, caused by living organisms. They form specific communities that interact in many different ways with mineral materials and their external environment. This complex phenomenon occurs in conjunction with many physical and chemical destructive processes. Thus, it is difficult to distinguish an extent of the damage caused by biotic factors from that resulting from abiotic ones. However, according to US estimation, thecontribution of microorganisms to the deterioration of materials as a whole may be within the range of 30% [12]. Biodegradability of various mineral building materials including the concrete is mostly due to the increased concentration of carbonates and inorganic sulfur compounds, as well as other chemically aggressive reagents of either abiotic or biotic nature. Their interactions with components of the mineral materials play an essential role in their corrosion induction and process [13]. Bio-deterioration of materials can take the form of bio-corrosion orbiofouling. Corrosion of metals is believed to be an electrochemical process, which results in oxidation of a metal to its oxide and hydroxide thereby distorting the structural integrity of the metal. Although the electrochemical nature of corrosion remains valid, microorganisms influence metal corrosion by modifying the metal solution interface through biofilm formation [14-15]. The rapid and moderate deterioration chemicals on the concrete are listed in Table-2 [16]. Some biogenic organic acids (acetic, lactic, butyric and the like) and carbon dioxide are extremely high corrosive towards the concrete. Biogenic mineral acids are very corrosive, especially the nitric acid produced by nitrification bacteria, as well as the sulfuric acid produced by sulfur oxidizing bacteria (SOB). They oxidize also the biogenic hydrogen sulfide (H_2S) which is a gas liberated into the environment by sulfate reducing bacteria (SRB). All these chemical substances of biological origin easily react with components of the concrete (Table-3) and cause its deterioration [17]. The biogenic chemicals are reacting with calcium hydroxide available on the surface of concrete. Few biogenic substances and their reactions are listed at Table-3 [18].

Table 3. Biogenic substances and chemical reactions essential for microbiologically influenced deterioration of concrete [18].

Biogenic organic acids
$Ca(OH)_2 + 2\ C_2H_4(OH)COOH + 3\ H_2O \rightarrow Ca[C_2H_4(OH)COO]_2 .5\ H_2O$
Lactic acid Calcium lactate
$Ca(OH)_2 + 2\ CH_3COOH \rightarrow Ca(CH_3COO)_2.H_2O + H_2O$
Acetic acid Calcium acetate
Biogenic carbon dioxide
$Ca(OH)_2 + 2\ CO_2 \rightarrow Ca(HCO_3)_2$
$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$
Biogenic nitric acid
$2\ NH_4^+ + 3\ O_2 \xrightarrow{Nitrosomonas} 2\ NO_2^- + 2\ H_2O + 4\ H^+$ $2\ NO_2^- + O_2 \xrightarrow{Nitrobacter} 2\ NO_3^-$
$Ca(OH)_2 + 2\ HNO_3 \rightarrow Ca(NO_3)_2 + 2\ H_2O$
Biogenic hydrogen sulfide and sulfuric acid
$SO_4^{2-} + 2\ H^+ + 4\ H_2 \xrightarrow{SRB} H_2S\uparrow + 4\ H_2O$ (SRB – Sulfate reducing bacteria)
$H_2S + 2O_2 \xrightarrow{SOB} H_2SO_4$ (SOB – Sulfur oxidizing bacteria)
$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4 .2\ H_2O$
Gypsum
$3CaO.Al_2O_3.3CaSO_4.nH_2O + 3(CaSO_4.2H_2O) + H_2O \rightarrow$ $3CaO.Al_2O_3 .3CaSO_4.32H_2O$
Ettringite

5. Concrete Sealer

Concrete sealers are applied to concrete for protecting it from surface damage, corrosion and staining. They either block the pores in the concrete to reduce absorption of water and salts or form an impermeable layer which prevents such materials from passing [19]. Research from major concrete authorities, including American Concrete Institute, Portland Cement Association, and National Ready Mix Concrete Association; confirm that most concrete damage is attributable to surface moisture intrusion. The most pervasive form of concrete damage is surface scaling from freeze/thaw. Other forms of damage include alkali-silica reaction (ASR), chemical intrusion, and corrosion of steel reinforcements. There is wide range of concrete sealers that offer varying degrees of protection to concrete. Each particular sealer has application, performance, maintenance, other characteristics and requirements that differentiate it from other sealers [20].

The influence of surface treatments on corrosion rates of steel in carbonated concrete was studied and concluded that water-repellant surface treatments that line the pores of concrete with hydrophobic layers, were effective in resisting water penetration and limiting the corrosion rate of steel in carbonated regions in the specimens exposed to cycles of wetting and drying [21]. The monomeric alkyl alkoxy silanes were found to be excellent water proofing agents and only a negligible amount of sealant was lost as a result of evaporation [22]. The two silanes (water-based, 40% solids and solvent-based, 40% solids) and one siloxane (solvent-based, 20% solids) exhibited much lower total chloride ingress values than the two epoxy and one sodium-silicate surface coatings [23]. The penetration of sealants into concrete in excess of 0.25-inches could only be achieved by using water repellents [24]. The effect of moisture in the concrete at the time of surface treatment application on the chloride intrusion and subsequent reinforcement corrosion was studied. The surface treatments used were a 40% silane solution, a 100% silane solution, a silane-siloxane two-coat system, and a silane-acrylic two-coat system. They concluded that all treatments reduced chloride in filtration, no one treatment was outstanding in this regard. Also demonstrated that 100% silane penetrated slightly better than 40% silane [25]. The performance of cement and epoxy based coatings in protecting concrete was evaluated. Results of that study indicated that epoxy modified cement-based coatings provide adequate protection to concrete [26]. A combination of "silane+siloxane" primer with an acrylic top coat was most effective treatment for corrosion resistance of reinforced concrete. No single coating could improve the resistance of concrete to all types of deterioration [27]. The double or triple coating systems were more effective for concrete durability than those with a single coating [28-29]. Only limited studies have been conducted to evaluate various surface treatments for better resistance of concrete to freeze/thaw damage or salt scaling [30]. Three concrete sealers, two crack sealants and two water repellent were evaluated under accelerated condition. The epoxy-based sealer T48CS and water repellent ATS-42 exhibited the best performance in protecting the concrete from salt scaling and featured the highest resistance to abrasion and generally lower water absorption rates and gas permeability coefficients. The results suggest that high resistance to both gas and water penetration is a crucial property in a good surface sealer, crack sealant or water repellent applied to concrete [31].

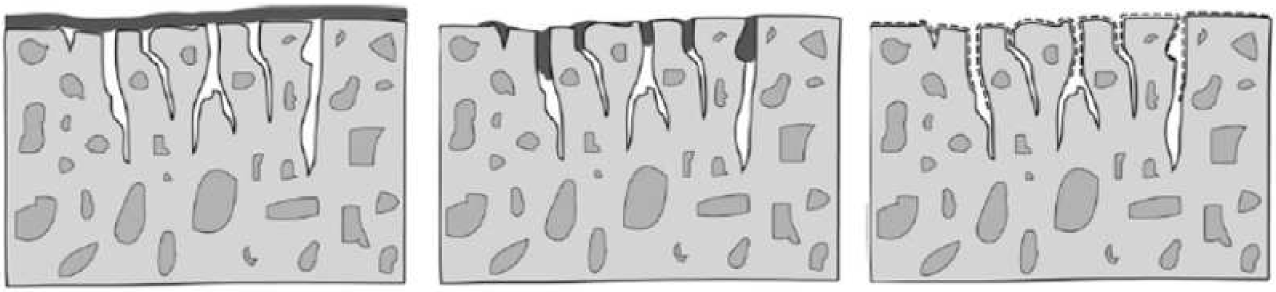
The concrete sealers or coating can protect the bridge concrete structure from damage caused by the aggressive environmental and chemical exposures [32]. Concrete sealers and coating have been applied as surface treatments into concrete surface to reduce the penetration of chlorides to protect concrete bridge structures against corrosion [33-34]. The chloride penetration resistance was investigated using a silane based sealer (SS1), an acrylic based coating (AC1) and two cementitious coatings (CC1and CC2) on concrete surface. They concluded that acrylic based coating (AC1) was the best performing coating, whereas cementitious coating CC1 had worst performance [35]. Five concrete sealers were evaluated for three groups of concrete mixes: normal, fly ash and old concrete to determine suitable sealer and concrete mix combination to improve resistance to the deterioration of concrete properties [36].

5.1. Advantages of Using Concrete Sealers for Surface Treatment

- Provide water repellency.
- Treated surface is breathable.
- Reduced maintenance and prevents steel corrosion.
- Non toxic and eco-friendly in nature.
- Block penetration of dust, oil, chemicals and other contaminants.
- Enhance the colour of concrete surface.
- UV resistance.
- Protect concrete against chloride ion ingress.
- Increase concrete compressive strength and surface hardness.

5.2. Types of Concrete Sealers

Concrete sealers are typically classified into: (1) Topical (coating) and (2) Penetrating sealers. However, penetrating sealers can be further defined by: (2a) Pore blocking types or (2b) Water repellents. Cady [37] suggested that sealers can be classified as (a) Barrier coating, (b) Pore blockers, and (c) Water repellents.



(a) Barrier Coating (b) Pore Blocker (c) Water Repellent

Figure 1. Sealer Types [26, 38].

5.3. Topical Sealer

Topical sealers can provide visual enhancement as well as protection from stains and chemicals. They are acrylic, epoxy and urethane sealers. They require a dry, clean surface during application to gain adhesion. They may alter the coefficient of friction which can make substrates slick when wet – a condition that can be remedied by adding anti-skid materials. Life span is generally 1-5 years.

5.4. Penetrating Sealer

Penetrating sealer can be applied to dry and damp surfaces and should be properly matched with substrate porosity in order to effectively penetrate the surface and react. The chemical reaction bonds active ingredients within the substrate blocking surface moisture. Life span is generally 5 or more. Penetrating sealers, including silanes, siloxanes, silicone and blended products, are a cost-effective means of protecting new and existing concrete surfaces. When applied properly, penetrating sealers can serve as chloride screens and damp proofing to improve durability against destructive corrosion of embedded reinforcement and damage from freezing and thawing. They penetrate the concrete surface and react chemically to form a water- repellent layer. Water usually will bead up on a treated surface. However, water trapped in the concrete or which soaks in can escape from the treated surface as vapor. These sealers have little or no effect on the concrete surface coloring. In addition to helping repel water and chlorides, sealers also help minimize penetration of dirt, grease, and oil, making surfaces easier to clean.

Chemical nature of concrete sealers and their properties are as follows:

5.5. Silicone Concrete Sealers

Silicone concrete sealers are inorganic-organic polymers with the chemical formula $[R_2SiO]_n$, where R = organic groups such as methyl, ethyl, and phenyl. Silicones have great hydrophobic (water repellent) and oilophobic (oil repellent) properties. Silicones are very short lived. They are UV unstable and do not hold up well to abrasion. It should be considered for vertical surface that may be prone to graffiti, a constant maintenance of silicone can help make clean up a lot easier. Silicone concrete sealers require reapplication every one to three years to maintain protective barriers. Horizontal surfaces will likely only last a few months, and less when exposed to UV radiation.

5.6. Silane Concrete Sealers

Silane concrete sealers are silicon analogue of an alkane hydrocarbon. Silanes consist of a chain of silicon atoms covalently bound to hydrogen atoms. The general formula of a silane is Si_nH_{2n+2}. Silanes tend to be less stable than their carbon analogues because the Si-Si bond has a strength slightly lower than the C-C bond. Oxygen decomposes silanes easily, because the silicon-oxygen bond is quite stable. If saturation of sealer occurred then exhibiting oilophobic and hydrophobic properties. If the concrete is sealed with a heavy application life spans of 5 to 8 years can be achieved. They are hydrocarbon based and as such can allow chemical chains to remain active in the concrete. Upon disappation (after a year or so) or upon too light of application, this active chemical chain is looking for other chemistries with which to react. This can produce a permanent stain in the concrete that can never be cleaned except through removal of the concrete. This makes silanes less attractive for stain resistance.

5.7. Silicate Concrete Sealer

Silicate concrete sealer helps to significantly reduce porosity in most masonry products such as concrete, stucco, plasters. They work by creating a chemical reaction with the excess $Ca(OH)_2$ in the concrete that permanently binds the silicates within the concrete making them far more wearable and water repellent. Most silicates are a very small molecule, which means they must be built from the "bottom up" in the concrete. Cady [37] reports that sodium silicate is the most commonly used silicate (72 %) while the reminder is split somewhat evenly between potassium and fluorosilicates. The silicates are effective sealers as the result of SiO_2

precipitating in the pores [22]. The silicate reacts with excess calcium present in the outer surface region of the concrete to form relatively insoluble calcium-silicate hydrate [23]. Sealing concrete with soluble sodium silicate may improve surface properties such as hardness, permeability, chemical durability and abrasion resistance [39].

5.8. Siliconate Concrete Sealer

Siliconate concrete sealer also significantly reduces porosity in concrete, stucco, plaster and cementitous chemistries. Like the silicates they seal by forming a permanent chemical change in the concrete dissolving the calcium hydroxide, reacting with it and other alkalis to form a new - nonsoluable chemicals. However, they are usually a larger molecule, offering more surface protection. Hydrophobic response is more obvious in the siliconate family than in the silicate. The siliconates are usually bead water quite well, and they continue to resist water in the form of water sheeting for years there after. Siliconate concrete sealers can be use for reducing moisture and freeze thaw damage and stains. Siliconates dry within concrete, thereby not changing the appearance or the texture of the concrete surface.

5.9. Acrylic Concrete Sealers

These are a polymethyl methacrylate (PMMA) or poly(methyl 2-methylpropenoate) the synthetic polymer of methyl methacrylate suspended in water or a solvent based material. They are brittle, often will yellow or can delaminate with age. Acrylics seal by forming a film over the surface of the concrete. Since they are coating based usually two coats are required. Two lighter coats works better than one heavy coat. More shine is achieved by adding more coats. Acrylic is a single-component polymer. They are water-clear, heat and UV resistant. Acrylic sealers are fairly easy to use and relatively inexpensive. Acrylics offer fairly good stain protection but are easily scratched. Acrylics are not resistant to most solvents like acetone, toluene or xylene.

5.10. Epoxy and Urethane Concrete Sealers

There are a huge number and variety of epoxy and urethane coating sealers. The epoxy compounds required a very thick surface build sometimes with aggregate thrown in for look or abrasion resistance. They provide high chemical and abrasion resistance without looking like a chunk of plastic on the concrete. It is now possible to get a very smooth look in a very long lasting product. They provide chemical resistance, abrasion resistance and appearance on the concrete surface. Epoxy is a two-component system that chemically reacts when mixed. The reaction is irreversible and the end result is a very durable, very hard surface. Epoxies are expensive and because they require careful measuring and rapid application, can be a challenge to apply correctly. Epoxies are generally vulnerable to UV exposure and yellowing. Urethanes are very stain and heat resistant; provide good or excellent UV resistance.

6. Conclusion

Concrete is one of the strongest construction materials applied in centuries all over the world. It is a heterogeneous material which is usually composed of the portlant cement, aggregates, water and admixture (optional). In concrete, cement paste is the primary active constituent. The properties and performance of concrete is determined by the hydration of cement paste. The deterioration of reinforce concrete structures is influenced by microbes in aggressive environment [40]. It has been found that bio-deterioration of concrete structures may increase concrete porosity and accelerate the diffusion of materials and increase corrosion processes, causing a significant loss of capacity. Concrete is also destroyed by material limitations, poor quality design and construction practices, as well as the hard exposure condition [13]. Many chemical substances including acids, alkalis, gases, oils/fats, sugars and many others very corrosive agents are responsible for chemical corrosion of concrete.

The cement hydration results formation of calcium hydroxide which reacts with carbon dioxide to form calcium carbonate. Resulting calcium carbonate is sparingly soluble and its formation causes tightening of the cement paste and increase in the concrete compressive strength. This process called concrete carbonation is considered favorable for this material properties. However, carbonates formation leads to the concrete shrinkage increase during drying, thus promoting the material cracking. Besides, concrete carbonation leads to its lower alkalinity and subsequently to corrosion of steel reinforcement.

Applications of concrete sealers for protection of reinforced concrete surface has several advantages such as water repellency, UV and heat resistance, protect concrete against chloride ion ingress, etc. Concrete sealers come in both water based and solvent based. All types of concrete sealers have valuable and practical application. The surface preparation for application of concrete sealer is a crucial part to achieving complete success after sealing. A surface being sealed must be clean from all dirt, dust and other contamination that will keep the sealer from adhering to the concrete surface. Surface preparation, following manufactures suggestions is recommended to achieve the best performance. Surface preparation for penetrating sealers is critical in order to achieve better penetration depth. Applying a sealer can be an effective and initially inexpensive method for increasing service life of reinforced concrete. There are commercially available penetrating sealers that are reported to penetrate deep into the porous concrete surface and thus provide protection for the concrete. Today, high quality concrete sealers can block up to 99 % of surface moisture [19]. The concrete sealers enhance the appearance of the concrete without degrading the look. They resist etching from UV degradation and yellowing from sunlight, acidic chemicals, food, oil, bio-deterioration and other common household materials. Concrete sealers are sensitive to environmental conditions during application and drying, including air temperature, humidity, concrete moisture content and temperature, wind, direct sunlight, possibility of rain, etc. This is especially true for water-based products, where proper drying is highly dependent on temperature and humidity. Each manufacturer, in turn, may have differing application requirements even for the same class of compound further making comparisons of test results difficult. Climatic conditions include temperature, wind, antecedent precipitation as well as forecasted precipitation. Most sealers are suggested to be applied between 4°C and 32°C at the concrete surface. The condition of concrete greatly affects sealer performance.

The primary conclusions are as follows:

1. The successful application of concrete sealer into reinforced concrete surface protect it from ingress of water, soluble salts and other contaminants and also extend its service life. It also provides protection from destructive freeze/thaw cycles in exterior environment as well as for embedded reinforcing steel.
2. Concrete sealer penetration into concrete can be controlled by proper selection of sealer for specific concrete.
3. Dual treatment system involving the application of two different concrete sealers together or in combination with other products has advantages, over the use of a single treatment.
4. The timing of reapplication of concrete sealer has been varying based on exposure, condition, location and traffic. The higher traffic and UV exposed surface of concrete should be resealed with appropriate sealer after every 2-3 years, while lighter traffic and interior surface should be resealed after every 4-5 years.
5. A concrete sealer that performs the best in laboratory trials may not perform well in the field. Determining the best performing compounds in the laboratory should be followed by field trials on the surface of concrete to be sealed to confirm their performance.

Recommendation

Since there are no national standard testing protocols are available. Hence, following steps must be done for finalizing suitable concrete sealers for protection of specific reinforced concrete from deterioration:

1. Understand the material and engineering properties of concrete surface to be sealed, requirement of sealing and final expectations of client after sealing.
2. Collection of commercially available concrete sealers based on their chemical composition and properties.
3. Proper surface preparation as per manufactures installation guideline. Existing concrete surface should be thoroughly clean and reasonably dry before application of the sealer.
4. After understanding expectations of client and properties of concrete surface to be sealed, the following tests to be done in the laboratory using various commercially available concrete sealers and their mixtures (as dual treatment):

a). Water vapor transmission

b). Saltwater absorption

c). Chloride permeability

d). Sealer penetration depth or coating thickness

e). Resistance to alkali

f). Ultraviolet (UV) weathering and cyclic saltwater ponding

g). Freeze-thaw resistance

h). Accelerated aging test on the surface of concrete beams / cylinders.

i). Field trial on the surface and monitoring.

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