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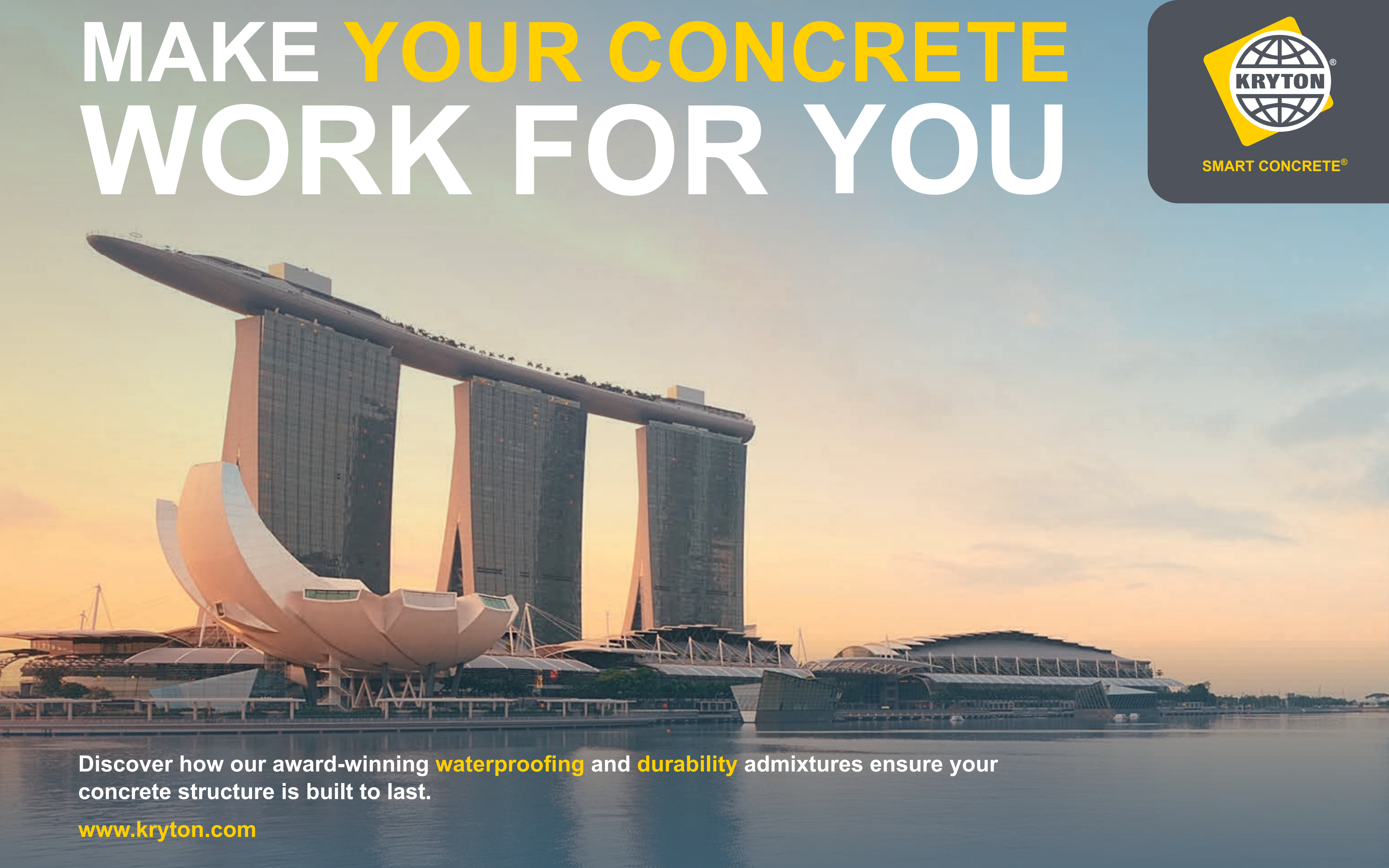
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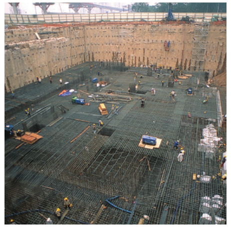


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INNOVATIONS IN PROTECTING

Construction Joints

Does crystalline coating also protect rebar?

By Alireza Biparva

All images courtesy Kryton International

Proper waterproofing of construction joints plays a vital role in fortifying below-grade concrete structures. Construction joints are stopping places—caused by non-continuous concrete pour—and a plane of weakness. Hence, they represent the most vulnerable part of the structure from a waterproofing perspective.

Without an effective joint waterproofing system known as a waterstop, it is not a matter of if the joint will leak, but rather, when it will leak. Leakage or dampness not only impacts the serviceability of the structure, but also causes major deterioration such as corrosion of reinforcing steel in concrete. Water penetration is a global problem as it reduces the service life of concrete structures. It is responsible for more than 80 per cent of damage to reinforced concrete facilities, thereby continuing to rack up the repair costs for owners and developers.

Traditional method

One of the technologies used to waterproofing joints is a polyvinyl chloride (PVC) waterstop, also known as the traditional "dumbbell" due to its shape. These plastic sheets are placed across the joint before the concrete is poured to create a physical barrier for blocking water penetration. This type of waterstop relies on the ribs in the design to prevent water from passing through the joint. The PVC waterstop is great for blocking water, and is relatively inexpensive, but has limitations. Improper compaction around the waterstop creates a pathway for water—PVC waterstop can bend while concrete is poured, forming a tunnel and area where water can infiltrate. This does not mean the waterstop is not working; an installation deficiency or concrete compaction is causing leakages. To make matters worse, it is virtually impossible to recognize the problem until the joint begins to leak, which is too late. Additionally, when PVC is considered as a single barrier, water can seep in until it reaches the waterstop. As you can see in Figure 1 (page 47), the rebar on the water side of the joint is exposed to the water and will corrode.

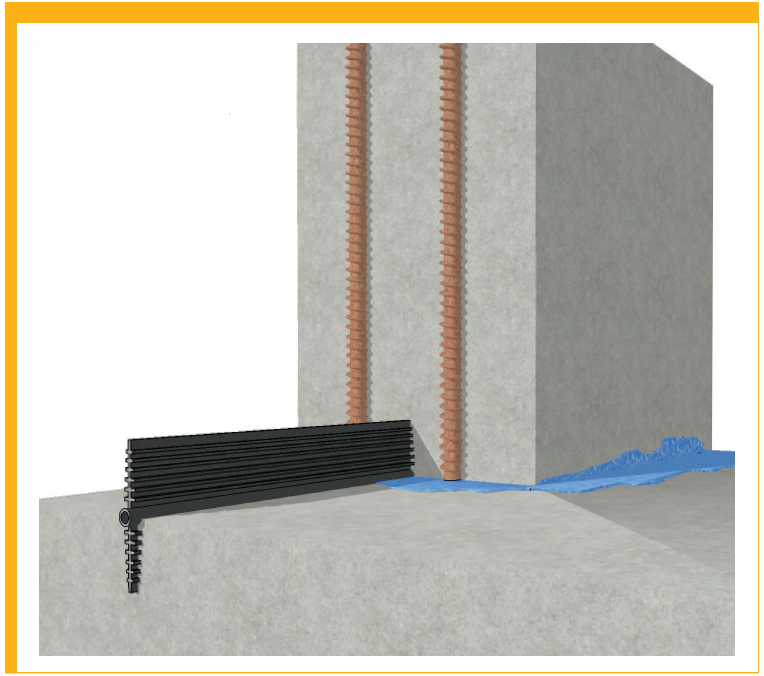
Alternative methods

These difficulties have opened the door for other waterstop systems such as hydrophilic swelling strips and crystalline waterstop coating.

The swelling waterstop is a synthetic rubber strip designed for waterproofing construction joints. Synthetic rubber swelling strips act as a physical barrier and can swell up to 1000 per cent of original volume to seal the construction joint and stop water flow. Its ability to swell and block water intrusion, not only under hydrostatic conditions, but also when facing salt or contaminated water, sets it apart from other products. This is important considering the state of the moisture in below grade and marine environments.

Crystalline waterstop coating is a powder mixed with water to a slurry consistency, and brushed on the joint area. It utilizes advanced integral crystalline waterproofing (ICW) technology to block the movement of water through concrete joints and acts as a chemical barrier. The crystalline waterstop coating exhibits a hydrophilic property, meaning, the special chemicals in the coating react on exposure to water, allowing millions of long, needle-shaped crystals to grow deep into the concrete mass. These crystals permanently block and prevent the passage of water through capillary pores, micro-cracks, and joints, thereby making the joint waterproof. As long as moisture remains present, crystals continue to grow throughout the concrete. Once the moisture content is reduced, the crystalline chemicals lie dormant until another dose of water causes the chemical reaction to begin again.

Figure 1



A polyvinyl chloride (PVC) waterstop is traditionally employed to waterproof construction joints.

Crystalline waterstop coating can be used in conjunction with a swelling waterstop at all static concrete-to-concrete joints where water penetration is a concern. This is called a double protection system. Crystalline waterstop coating as single protection can also be employed as a dampproofing treatment when the joint is subjected to water with low or no hydrostatic pressure. Since crystallization takes some time to occur, corrosion of rebar on the wet side is a concern in both single and double

Yellow synthetic rubber swelling strips acts as a physical barrier and can swell up to 1000 per cent its original volume to seal the joint and stop water flow.

protection systems as it is with the PVC system (Figure 2). However, testing has demonstrated the coating not only acts as a chemical barrier to prevent water penetration, but also protects the rebar.

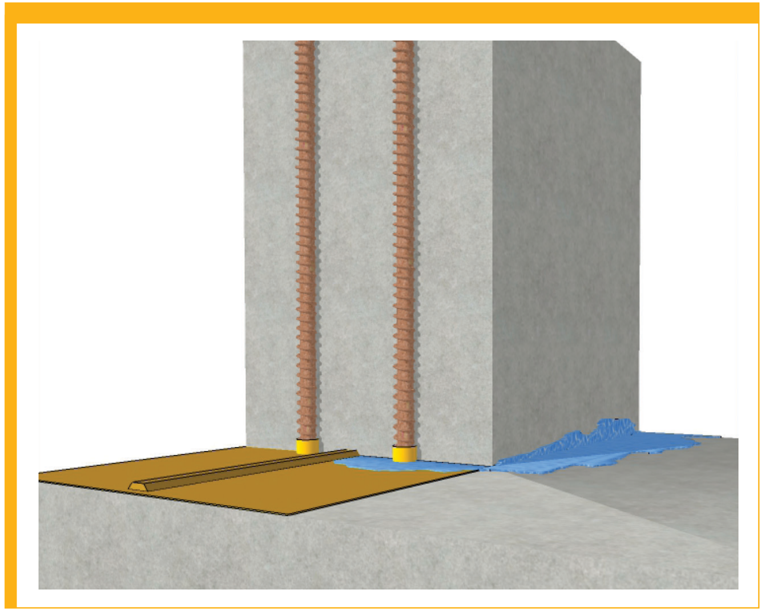
To investigate the effects of crystalline coating, a joint research study was conducted by a concrete and waterproofing solutions manufacturer and a University of British Columbia co-op student. This study was performed in two phases at the Kryton Research Centre, Vancouver, in December 2016. In the first phase, half-cell potential measurement, as well as visual inspection, was used to analyze the corrosion mitigation of coated steel reinforcing bars embedded in concrete. In the second phase, in parallel to the corrosion tests, a modified pull-out test was employed to assess the bonding of the materials with concrete and steel.

Phase 1: Corrosion

Overall, when the coating is applied at the joint, the interface and bottom section of rebar are coated with crystalline coating. Hence, when water penetrates through cracks, it contacts the coated rebar instead of the rebar directly. Thus, in this phase, the corrosion resistance of reinforcement steel with crystalline waterstop coating was compared with uncoated rebar. The coating was applied to some samples. After curing, the coated and uncoated samples were directly immersed in a sodium chloride (NaCl) solution for a certain period. This setup simulates a marine environment.

At the end of each testing period, a visual inspection of the specimens was conducted to compare the level of corrosion. Additionally, a half-cell potential measurement device was employed to monitor the corrosion process of the specimens in accordance with ASTM C876-09, *Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete*. Further, the potential readings were analyzed in accordance

Figure 2



A double protection system with both crystalline waterstop coating and a hydrophilic swelling strip protects the rebar.

to the International Union of Laboratories and Experts in Construction Materials, Systems, and Structures' (RILEM) book TC-154, *EMC: Electrochemical Technique for Measuring Metallic Corrosion*.

After monitoring the samples for 28 days, half-cell potential measurements showed crystalline coating material directly applied on the rebar surface, dramatically delayed the corrosion activity compared to the control (uncoated) samples. These results were also confirmed by a visual inspection (Figure 3).

Phase 2: Bonding

Previous studies have shown any coating on the reinforcement bars in concrete structures could affect the ultimate bond strength of the rebar. Therefore, as part of this research project, it was critical to assess the impact of crystalline coatings on the bond strength of embedded rebar with surrounding concrete. One of the most commonly used test methods for assessing the ultimate bond strength of embedded rebar is the pull-out test. According to RILEM book RC 6, *Bond test for reinforcement steel*, five samples are needed to make the comparison in this test.

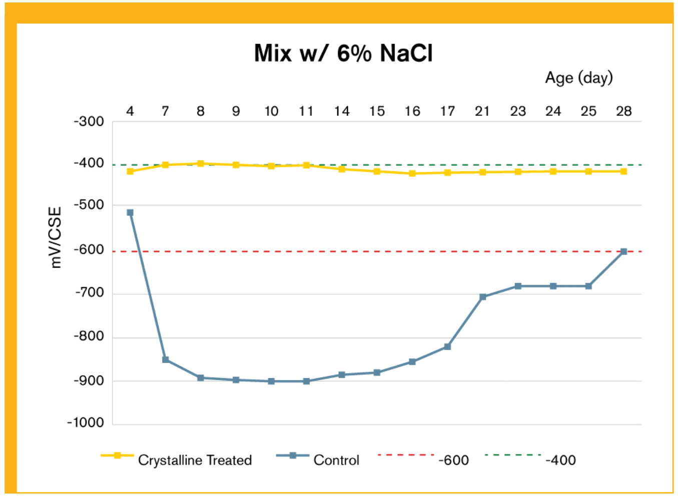
Therefore, 10, 10M black steel rebars were cut into 152 mm (6 in.) pieces. After cleaning the bars, crystalline coating was brushed onto five rebars. The coated bars were then cured for hardening. After 24 hours of initial curing, the coatings had sufficiently hardened. The bars were then placed into cylindrical-shaped moulds. A batch of concrete was prepared in accordance with ASTM C192, *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*, and poured into the cylindrical moulds. Filled concrete moulds were transferred into the curing room, covered with plastic tenting, and sprayed with water every day for 28 days. After 28 days of curing, the specimens were subjected to a modified pull-out test using a compression machine.

The results show the crystalline coating did not reduce the bond strength of the reinforcement steel bar with its surrounding concrete, but increased this ultimate bond strength by 3.85 per cent. The control (untreated rebar) had a bond strength of 5.501 MPa (797.8 psi) while the treated sample had a bond strength of 5.717 MPa (829.18 psi).

Conclusion

Based on the complexity of new buildings, limitations of traditional methods, and the goal to make more sustainable structures, advanced waterproofing solutions, especially for high-risk areas such as construction joints, seem necessary. Crystalline coating and swelling waterstop can provide a reliable barrier and prevent water penetration through the joint during its service life. The solution not only prevents water penetration, but also has the potential to reduce the corrosion of rebar in concrete without any negative effects on the ultimate bond strength.

Figure 3



Half-cell potential measurements over 28 days of control (uncoated) and coated rebar embedded in 6 per cent sodium chloride (NaCl) concrete and immersed in 3.5 per cent sodium chloride water.

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Crystalline Waterproofing

and Protection for Concrete

By Dave Ross

All images courtesy Xypex Chemical Corp.

Concrete has been used for thousands of years and is the most widely used building material in the world. According to the Cement Association of Canada (CAC), more than twice as much concrete is used in construction around the world than the total of all other building materials, including wood, steel, plastic, and aluminum.

Yet, despite its apparent solidity, strength, and durability, concrete is porous and permeable to fluid and vapour infiltration and migration. Water and dissolved chemicals, such as chlorides, sulfates, and acids, can penetrate deep into concrete, sometimes resulting in premature damage, such as reinforcing steel corrosion, freeze/thaw cracking, spalling, and chemical attack.

Added to this 'natural' porosity is the fact newly poured concrete develops cracks. This can be due to excess water, rapid drying, improper strength, settlement, and shrinkage. When it comes to building foundations, elevator pits, water/wastewater treatment and water containment structures, and many other applications, waterproofing and protecting the concrete is critical.

The porous and permeable nature of concrete

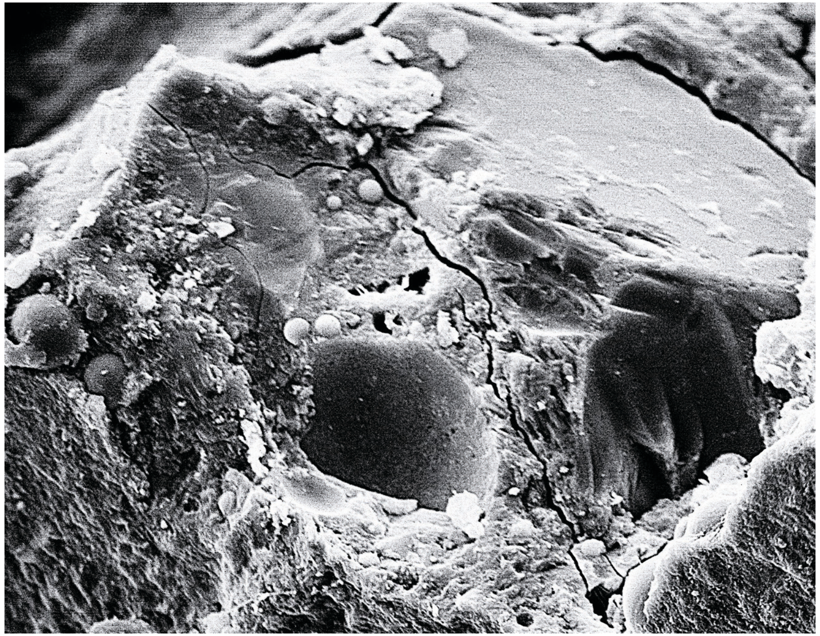
Concrete is a mixture of rock, sand, cement, and water. Rock and sand form the aggregate base of the concrete. The mixture of cement and water provides a paste, which binds the aggregates together. As the cement particles hydrate and form calcium silicate hydrates, the whole mixture hardens into a solid, rock-like mass.

To make this mixture workable, easy-to-place, and consolidate, more water than necessary is used to hydrate the cement. This extra water, known as the water of convenience, bleeds out of the concrete, leaving behind pores and capillary tracts.

Despite the use of admixtures to reduce the amount of water in the mix, pores, voids, and capillary paths form in the concrete. They carry water and aggressive chemicals that corrode steel reinforcement and deteriorate the concrete, thus jeopardizing the structure's integrity.

Porosity is the amount of holes or voids left in concrete, expressed as a percentage of the total volume of a material. Since it is porous, concrete is also permeable.

Permeability—a broader term than porosity—is an expression of how well the voids are connected, providing the ability of water to flow through a material. Together, these pathways allow the movement of water into and through the concrete. Permeability is described by a quantity known as the 'permeability co-efficient,' also called Darcy's Co-efficient. The water permeability of concrete is a good indicator of its quality and durability. The lower the permeability co-efficient, the more impervious the concrete and the higher its quality and performance. Nevertheless, concrete with low permeability may still need a waterproofing agent to seal micro-cracks.



Magnified view of micro-crack.

Vapour flow in concrete structures

Water can also migrate through concrete in the form of vapour. The flow travels from high vapour pressure, generally the source, to low vapour pressure by a process of diffusion and can vary based on environmental conditions.

Vapour flow direction is critical when applying a waterproofing treatment in situations where an unbalanced vapour pressure gradient exists. Some typical examples of this are as follows:

- applying a low vapour permeable membrane, such as a traffic deck coating over a damp concrete surface (even if the very top surface is dry) on a warm day results in the buildup of vapor pressure and pin-holing or blistering;
- adding a coating or sealant to the outside of a building wall may trap moisture if the sealant is not sufficiently vapour permeable; and
- installing low vapour permeable flooring over a slab-on-grade with high subsurface moisture content may result in delamination.

As a general rule, a coating with low vapour permeability should not be placed on the downstream face (negative or dry side). Either vapour or water pressure will 'push' the coating from the surface, causing it to blister. Some types of coatings (*e.g.* cement-based ones) and water permeability-reducing admixtures accommodate considerable vapour movement, thus allowing them to be placed successfully on the downstream side.

How crystalline waterproofing works

Crystalline waterproofing technology improves the waterproofing and durability of the concrete by filling and plugging pores, capillaries, and micro-cracks with an insoluble, highly resistant crystalline formation. The process is based on two simple properties—one chemical and the other physical.

Concrete is chemical in nature. When a cement particle hydrates there is a reaction between water and the cement, which causes it to become a hard, solid mass, but there are also chemical byproducts given off that lay dormant in the concrete.

Crystalline waterproofing introduces a second set of chemicals. When these two groups are brought together (*i.e.* the byproducts of cement hydration and the crystalline chemicals) in the presence of moisture, a reaction takes place, resulting in the formation of an insoluble crystalline structure.

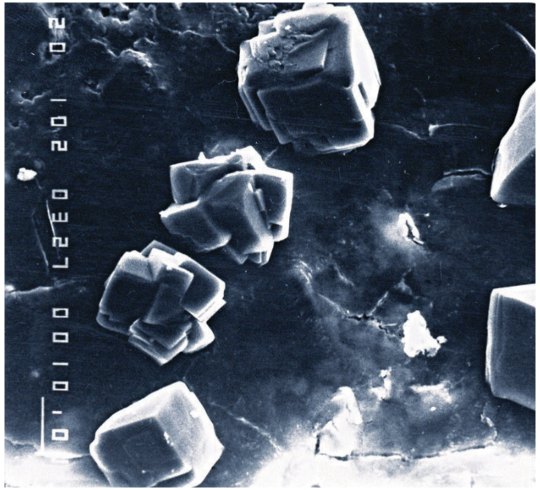
This crystalline structure can only occur where moisture is present, and thus, will form in the pores, capillary tracts, and shrinkage cracks in concrete. Wherever water can penetrate the concrete, the crystalline formation will follow.

When crystalline waterproofing is applied to the surface as a coating, a process called chemical diffusion takes place. The theory behind diffusion is a solution of high density migrates through a solution of lower density until the two equalize.

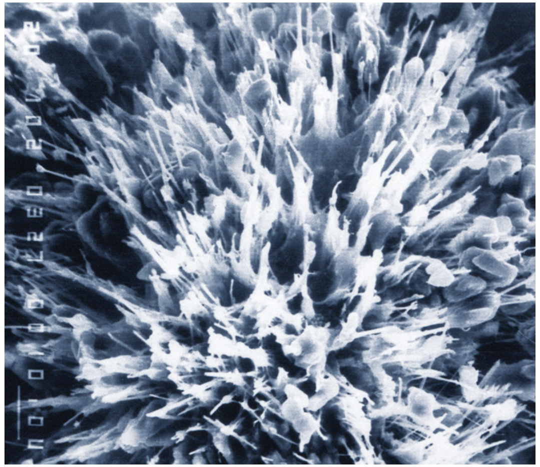
Water-filled capillary tracts contain a solution of low chemical density. When crystalline waterproofing is applied to this concrete a solution of high chemical density is created at the surface, triggering the process of diffusion. The crystalline waterproofing chemicals must now migrate through the water (the solution of low density) until the two equalize.

The crystalline waterproofing chemicals now spread through the concrete and become available to the byproducts of cement hydration, allowing the chemical reaction to take place and the formation of a crystalline structure. As chemicals migrate through water, this crystalline growth will form behind an advancing front of chemicals. This reaction continues until the crystalline chemicals are either depleted or run out of water.

Chemical diffusion can take these chemicals about 300 mm (12 in.) into a completely saturated concrete substrate. Where concrete is not completely saturated, the crystalline chemistry only diffuses to the depth of water saturation, but still has the potential to travel deeper into the concrete in the future if water penetrates from the opposite direction, thus reactivating the crystalline chemistry.



Scanning electron microscope (SEM) view of a concrete pore.



SEM view of a concrete pore as it fills with multiplicative crystalline formation.

Instead of just reducing the porosity of concrete, like water reducers, plasticizers, and super plasticizers, the crystalline formation engages the material filling and plugs the voids in concrete to become an integral and permanent part of the structure.

Since the crystalline formation occurs within the concrete it cannot be punctured or otherwise damaged like membranes or surface coatings. Crystalline technology also improves the durability of concrete structures, lowering their maintenance cost and extending their lifespan by protecting them against the effect of aggressive chemicals. Crystalline waterproofing is resistant to chemicals where the pH range is between three and 11 under constant contact and two to 12 under periodic contact. Crystalline waterproofing tolerates temperatures between –32 C (–25 F) and 130 C (265 F) in a constant state. Humidity, ultraviolet (UV) light, and oxygen levels also have no impact on the material's ability to perform.

Crystalline waterproofing offers enhanced protection against the following agents and phenomena.

Carbonation
This is the result of the dissolution of carbon dioxide (CO_2) in the concrete pore fluid, which reacts with calcium from calcium hydroxide and calcium silicate hydrate to form calcite ($CaCO_3$). This process reduces the pH of concrete and its natural protection of reinforcing steel.

Alkali aggregate reactions
By denying water to these processes, crystalline waterproofing helps prevent these types of swelling reactions.

Chloride attack
Extensive chloride-ion diffusion testing shows concrete structures protected with a crystalline waterproofing treatment slows the diffusion of chlorides, thus extending the time-to-corrosion of the reinforcing steel.

Due to their limitations, membranes and coatings may leave concrete susceptible to water and chemical damage. The addition of crystalline technology can seal the pores and micro-cracks.

Matching the right crystalline technology with the application
Crystalline waterproofing and protection technology is sold in powder form and is mixed with water. It can be used in two ways:

- as a coating applied to the surface of existing or new concrete structures, such as foundation walls, floor slabs, or the inside of underground structures; and
- an admixture added directly into the concrete batch at the plant or truck for new construction, shotcrete, and precast applications.

Crystalline waterproofing coating
As mentioned earlier, when applied to clean, bare, and previously saturated substrate as a slurry mixture, the reactive chemical ingredients in crystalline waterproofing can penetrate up to 300 mm deep inside the concrete by using water as the migrating solution. As these chemicals penetrate through the capillaries and pores, the reaction with the mineral byproducts of cement hydration creates the crystalline formation that eventually fills the cracks and pores.

Crystalline waterproofing in water soluble bags is added to the back of a ready mix truck.

Crystalline waterproofing can be applied by a brush or with spray-on equipment. To ensure the success of the application, care must be taken to ensure correct surface preparation, substrate saturation, coverage rate, and curing time.

Since the crystalline waterproofing coating system has a unique chemical diffusing characteristic, proper surface preparation of the concrete is critical to the performance of the treatment. Concrete surfaces need to have an open pore texture to allow the transfer of the reactive crystalline chemicals from the coating into the concrete substrate. The surface also needs to be clean and free of form oil, laitance, and other foreign matter to ensure proper adhesion of the coating.

Crystalline waterproofing admixture

When used as an admixture the same chemical reactions take place, but cost is lowered by eliminating the labour associated with the application of a surface treatment. Additionally, the use of crystalline waterproofing as an admixture moves labour offsite, eliminating scheduling and delays.

Since the admixture is added to the concrete mix at the batch plant or a ready-mix truck, it ensures the crystalline formation occurs uniformly throughout the structure rather than penetrating from the surface as would be the case with a surface application. In addition to waterproofing, crystalline admixture can reduce shrinkage cracking as well as increase compressive strengths. This may be because the water is taken up into the crystalline structure, leading to a longer, internal moist cure that is beneficial for shrinkage reduction and compressive strength development. For most mix designs, the dosage rate is two to three per cent based on the Portland cement content.

While crystalline waterproofing admixture is compatible with super plasticizers, air-entraining agents, water reducers, fly ash, pozzolans, and other ingredients used to improve the performance of modern concrete mixes, it is best to check with the manufacturer to ensure there is no incompatibility with other elements of the concrete mix, particularly concrete set retarders.

Negative-side waterproofing

Where existing underground structures are experiencing water seepage because of failed exterior membrane or coating systems, the problem can be remedied by the application of crystalline waterproofing on the negative side (inside) of the structure. Under these conditions, surface coatings—depending on the adhesion—blister and peel when moisture seeping through the concrete from the exterior dissolves soluble minerals and deposits them under the coating in the form of efflorescence. Since crystalline waterproofing penetrates into the concrete and plugs the pores beneath the surface, it stops water seepage in the concrete before it reaches the inside surface. This does not depend on its adhesion to the surface and will not blister and peel off like surface barriers.

Vapour transmission through basement floors and walls is also a common problem leading to unpleasant damp, musty odours. Testing in Japan and Europe has shown the application of crystalline technology can reduce vapour flows as much as 50 per cent by reducing the size of the capillary tracts in the concrete as well as making some of them discontinuous, which, in most cases, provide a drier, more pleasant atmosphere.

A protective layer of crystalline waterproofing is applied to the Valdez Marine Terminal water purifying tanks in Prince William Sound, Alaska.

Crystalline waterproofing materials also have the ability to self-heal micro-cracks (<30 µm [1181 µin]) in the concrete substrate as well as macro-cracks up to 0.4 mm (16 mils) in width. The rate of self-healing is dependent on the size and nature of the crack (static or moving) and the hydrostatic pressure the crack may be subjected to. Self-healing can be evident in only a few days or as long as a few months depending on the ambient conditions.

Real-world examples

Several examples of how crystalline waterproofing technology products were used in real world construction applications situations are illustrated by the following projects.

May Bank Headquarters

The triple tower development designed as a new headquarter building for May Bank in Kuala Lumpur, Malaysia, involved diaphragm wall construction that incorporated a nine-level underground parking garage. A crystalline technology admix (dosed at 3 kg/m³ [0.19 lb/cf]) was selected for the project to assist with controlling hydration heat, reduce shrinkage cracking, give the slab the capacity to 'self-heal,' and waterproof the concrete as well as increase its strength and durability.

The basement slab required approximately 24,000 m (847,552 cf) of crystalline admix-dosed mass concrete. Commencing on September 26, 1997, the initial pour of approximately 13,200 m³ (466,154 cf) was conducted over a 60-hour period; it was then and remains today the third largest continuous pour conducted in the world and the largest in Southeast Asia.

Valdez Marine Terminal

Two coats of crystalline waterproofing were applied to the ballast water purifying facility's tanks at the Valdez Marine Terminal located at the end of the Trans Alaskan Pipeline System, Prince William Sound, Alaska. More than 25,000 m² (250,000 sf) of coating materials was applied to the two final water purifying tanks. The ballast water treatment system sends oily water through multiple processes to strip it of any hydrocarbons before it is released into the ecologically sensitive waters of Prince William Sound.

Columbia College

Columbia College is British Columbia's oldest university transfer college. The main campus is housed in a five-storey, 6782-m² (73,000-sf) building just east of Vancouver's downtown core at 438 Terminal Avenue. The building has a one-level, below-grade parking garage falling just above the sea level from the nearby False Creek Inlet. Due to the local climate and high-water table, the structure was subject to ongoing groundwater and below-grade hydrostatic pressure.

To waterproof the foundation slab, walls, and elevator pit, without the uncertainty and extra labour of membranes or coatings, the designers chose a crystalline admixture to add to the 500 m³ (17,657 cf) of ready-mix concrete required for the project. The crystalline admix was introduced at a two per cent dosage (based on the total weight of cementitious ingredients).

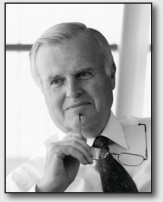
Crystalline waterproofing patching material and coating products were used in combination with a polyvinyl chloride (PVC) waterstop to permanently seal the joints where exterior walls landed on the slab. Additionally, crystalline waterproofing admix was also used as a modified grout to ensure a well-consolidated wall/slab interface. Once completed, all walls and joints in the foundation structure were dry and free of leaks.

Other applications

Crystalline waterproofing admix is also used by precast concrete producers to add value and enhance the performance of concrete pipes, manholes, septic tanks, and architectural panels. Apart from waterproofing these products, crystalline technology enhances chemical resistance and reduces shrinkage cracking, thus prolonging service life. Since it is sold in powder form, crystalline waterproofing can also be included in the mix design for bagged cement products such as shotcrete, mortar mixes, and stuccos.

Conclusion

Although concrete may appear to be a simple product to manufacture, it requires a highly engineered approach. In today's design and construction environment, where more stringent requirements, such as longer life cycles, more durable concrete, and value-engineering concepts are expected, careful consideration must be paid to not only the basic requirements, such as the water/cement ratio and materials, but also to more sophisticated chemical admixtures. With its ability to reduce the porosity and permeability of conventional concrete, crystalline waterproofing technology is a valuable addition to building sciences.



David Ross is the technical services director for Xypex Chemical Corp. of Vancouver, a manufacturer of crystalline waterproofing materials. He can be reached at dave@xypex.com.

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Waterproofing for Concrete Parking Structures: A Comparison

By James Cooper, P.Eng., LEED AP O+M

All images courtesy RJC Engineers

Owners, engineers, and contractors involved in the design, operation, maintenance, and restoration of parking garages and building podium decks need to understand the role and importance of waterproofing systems in protecting these facilities. When there is a lack of proper attention to these systems, repair and maintenance costs increase and anticipated service lives suffer.

Methods of protection for parking garages and podium decks have evolved and changed dramatically over the past 30 years. Old ways of thinking and design have given way to new understandings of deterioration mechanisms and protection needs—some of which are reflected in new requirements in the Canadian Standards Association (CSA) S413, *Parking Structures*. The increased understanding of how moisture and de-icing salts accelerate deterioration in concrete and steel structures has encouraged growth in this sector. The long-term performance of these buildings is directly related to the effectiveness of the waterproof barriers utilized to prevent moisture and de-icing salt contamination, as well as the management of the salt-laden water entering the facility.

By effectively protecting the structure and maintaining waterproofing systems in a state of good repair, owners can slow down the rate of deterioration and allow for safe, uninterrupted use of the building for a long time. The structure's protection also ensures stability in the value of the asset by limiting deterioration and closures, and reduces long-term capital expenditure costs. On the other hand, the failure of waterproofing systems often results in economic losses, including damage to building occupant vehicles, expensive structural repair costs, and opportunity losses during repair work as a result of parking garage closures. A functional waterproofing system is, therefore, the front line of defence for any structure subjected to vehicle use and de-icing salts.

Understand one's needs

Deciding to protect a structure with a waterproofing system is a simple and necessary step. However, determining the specific waterproofing requirements to meet the structure's needs for the long term is more difficult. It is important to understand the critical elements to look for in an effective waterproofing system.

Prevent leakage

The obvious purpose of a waterproofing system is to prevent the flow of water and dissolved salts into and through the structure onto vehicles or into the occupied space below. Careful consideration and effective detailing at termination points, drains, pipe penetrations, cracks, and joints are required.

Prevent chloride (salt) ingress at cracks

Nearly all parking garage surfaces are concrete. With very little exception, concrete does one thing really well—cracking. An effective waterproofing system must therefore bridge cracks, which will open and close as a result of temperature changes and cyclical loading over the structure's lifespan. If the system cannot continue to bridge cracks, it becomes an easy avenue for moisture and chlorides to circumvent a surface-applied waterproofing system.

Provide a non-slip surface

Slip resistance is important for vehicles and pedestrians as they travel through a structure. Health and safety of users is negatively impacted if a waterproofing system becomes slippery—when wet or with time. Therefore, initial and long-term slip resistance mechanisms are necessary.

Provide a durable wearing surface

A poorly designed waterproofing system can wear with use, or deteriorate due to specific environmental factors. Accelerated wear and deterioration may significantly impact performance and service life. A waterproofing system must withstand the aggressive environment in which it operates, retain adequate functionality, and meet its required service life. Worn waterproofing may quickly lose slip resistance, and deteriorated installations cannot effectively prevent moisture and chloride ingress into the structure. Critical areas with increased vehicle loading (*e.g.* loading docks, truck traffic areas, and drive aisles) often require more robust designs to meet similar service lives as other areas.

An example of deterioration of a thick waterproofing system on a roof deck.

Obtain required bond strength

A waterproofing system is only going to provide protection when it remains bonded to the surface on which it is installed. A system that does not stick will fail to adequately protect the structure below. Therefore, a waterproofing assembly must be selected based on achievable substrate preparation requirements because site constraints can inhibit the preparation work needed for a specific system. Such constraints can include restrictions on large construction equipment, noise/dust generating restrictions due to occupancy, or schedule constraints that may fast track repairs.

Consider snowplow resistance

A waterproofing system must be specially designed to resist damage and perform adequately on open parking and podium decks as well as roof parking levels where snow removal is undertaken. It is equally important to have a proper maintenance plan to ensure snow removal is undertaken with minimal impacts to the waterproofing. A hard wearing surface and high bond strength will often correlate with damage resistance. Ideally, the waterproofing layer will be physically separated from the driving surface by a topping or asphalt wearcourse to provide greater protection against snowplows.

Provide ultraviolet stability

A waterproofing system exposed to sunlight must withstand the damaging effects of ultraviolet (UV) radiation because sunlight can physically break down some waterproofing systems and reduce their effectiveness. Additionally, UV radiation can cause discolouration and other surface distress.

Ensure ease of maintenance and repair

Most waterproofing systems require localized repair and maintenance at some time during their anticipated lifespan to address localized deterioration and achieve the overall service life. A key consideration is how easy and cost-effective it will be to address potential deterioration. Each waterproofing system requires a specific repair approach that will impact the structure's operation in different ways and costs.

Code compliance

New parking structures must have waterproofing systems designed to be in conformance with CSA S413. This standard includes minimum design requirements to increase performance levels and durability. Attention to these code requirements is required to ensure proper implementation.

Cost

A waterproofing system should be economically feasible or it is of no use. The type of property and its expected service life may dictate the suitability of a high- or low-cost option (*i.e.* a class "A" commercial property compared to a mid-rise condominium building). However, high cost does not solely correlate to effectiveness for a particular situation.

Figure 1

Waterproofing Type	Scrapes Damage	Puncture Damage	Excessive Wear Damage	Snow Plow Damage	Tire Shear Damage	Failure Risk on Ramps
Thin Waterproofing (Polyurethane Waterproofing)	High	High	High	High	Moderate	High
Mastic Waterproofing (Asphaltic Waterproofing)	Moderate	Moderate	Low	Low	High	Moderate to low
Thick Waterproofing (Asphaltic Waterproofing)	Moderate	Moderate	Low	Low	High	Moderate to low
Thick Waterproofing (Concrete Topping on Hot Rubber)	Low	Low	Low	Low	Low	Low
Thin Waterproofing (Polyurethane-Methacrylate [PMMA] Waterproofing)	Moderate	Moderate	Moderate	Moderate	Moderate	High

Typical advantages and disadvantages of common waterproofing systems.

Traffic-bearing waterproofing systems

Waterproofing systems are often multilayered to obtain the benefit of distinct physical properties. Systems must be flexible, soft, and elastic to accommodate movement of the structure as a result of thermal and loading changes. At the same time, they must also be hard, strong, and durable to deal with vehicle wear and tear, snowplows, and environmental factors. These are seemingly competing properties and it may be hard to picture them working together as part of a seamless waterproofing system. To achieve both requirements, the properties are integrated at different locations: at the surface of the structure as a waterproofing membrane layer, and above this as a wearing surface.

Membranes
A typical waterproofing system consists of a flexible, fully waterproof barrier membrane located at the surface of the concrete slab. The membrane must be flexible and elastic to effectively prevent the ingress of moisture and chlorides into the structure and also withstand movement of the structure and cracks without tearing and cracking itself.

Wearcourse
The wearcourse is the component of a waterproofing system withstanding the abuse of the aggressive environment it is in. It is typically intended to protect the membrane from physical damage as a result of vehicular traffic. The wearing surface may be installed directly on, and bonded to, the membrane or may be physically separated from the membrane. The installation type depends on the system and design. While it may sound advantageous for the wearing surface to move with the structure and bridge cracks, it would then lack the other key characteristics required to handle vehicle loading (hard, durable, and impact- and slip-resistant).

Designing the system

Selecting the right waterproofing system is a challenge always unique to the structure, the owner's needs, and environmental factors in the installation environment. Proper selection requires a thorough understanding of available products and their performance characteristics.

Waterproofing systems are broadly grouped into two categories—thin and thick. These groupings have various systems within them comprising different materials affecting their properties and performance in various kinds of environments.

Polyurethanes
These are the typical "thin systems" on the market, and their chemical makeup consists of:

- **primer**: a polyurethane-based adhesive used to improve bond;
- **membrane**: a two-component, fast-curing, polyurethane basecoat designed with excellent elongation properties;
- **wearcourse (interior)**: a two-component, fast-curing, aromatic polyurethane topcoat with high tensile strength and excellent tear and abrasion resistance; and
- **wearcourse (exterior)**: a two-component, high-solids, aliphatic urethane waterproofing membrane.

These systems have urethane membranes and wearcourses fully bonded together as part of a single assembly. These systems are liquid applied with squeegees and rollers, have very high bond strengths to the concrete surface (>1.4 MPa [203 psi]), are comparatively thin (1.5 to 3 mm [60 to 120 mils]) and lightweight.

Hot-rubberized asphalt
Asphaltic waterproofing is typically considered a "thick system" as the finished assemblies can range from 20 to 150 mm (0.78 to 6 in.) or more in thickness.

Figure 2

Waterproofing Type	Ultraviolet (UV) Damage	Application Time	Relative Installation Cost	Relative Maintenance Costs	Expected Service Life (with typical maintenance)
Thin Waterproofing (Polyurethane Waterproofing)	High	Min. two weeks	Low	High	Moderate
Mastic Waterproofing (Asphaltic Waterproofing)	High	Min. two weeks	Medium	Medium	15 to 18 years
Thick Waterproofing (Asphaltic Waterproofing)	Low	Min. two weeks	Medium	Low	18 to 25 years
Thick Waterproofing (Concrete Topping on Hot Rubber)	Low	Min. three weeks	High	Low	20 to 25+ years
Thin Waterproofing (Polyurethane-Methacrylate [PMMA] Waterproofing)	Low	Two days	Very High	Low	15 to 20 years

Average application times and relative costs of common waterproofing systems.

These systems consist of a rubberized asphalt waterproofing membrane overlaid with a wearing surface (*e.g.* mastic, asphalt, concrete, or interlocking pavers). The hot-rubberized asphalt waterproofing is liquid applied with squeegees and reinforced with fabric. There are distinct advantages and disadvantages to each type of wearing surface including varying performance levels, weights, and anticipated lifespans. For example, a concrete topping installed above a hot rubberized waterproofing system provides a durable and long-lasting surface, which will withstand impact and not be prone to wearing. These systems can also utilize both electric or glycol embedded snow melting systems, thereby reducing the need for de-icing salts, and can significantly improve the slip resistance of ramps and loading areas.

New technologies

Most of the existing waterproofing systems have weaknesses, such as:

- components are easily worn;
- susceptible to impact damage;
- too heavy for a structure;
- too thick, leading to clearance issues;
- require a long curing period; or
- have disruptive smells.

Additionally, some application locations may require specialized approaches with innovative technologies to meet owner and user needs, as well as provide minimal shutdown periods, longer-term performance, and reduced maintenance cycles. Polyurethane-methacrylate (PMMA) thin traffic deck coating is a new technology attempting to address some of these barriers in the North American market.

PMMA

A PMMA assembly provides additional durability in areas where normal polyurethane systems may wear prematurely, such as the base of entrance/exit ramps, turning radii subjected to heavy traffic, and drive lanes that cannot be readily phased without impacting operations. One of the primary benefits of this system is installation can be accomplished in hours rather than the several days required for a typical polyurethane system. This can considerably limit disruption to an existing building.

Deterioration as a result ofwaterproofing failures.

Wearing surface application for a thin traffic deck coating system.

These systems typically consist of a methyl methacrylate (MMA) primer, a modified polyurethane methacrylate basecoat and wearcoat, and a 100 per cent MMA topcoat. Based on observations of these systems to date, the MMA offers excellent abrasion and chemical resistance and UV stability, greatly exceeding typical polyurethanes. Methacrylates are long lasting, stable compounds that do not change over time, and provide excellent resistance against abrasion, wear, stability against sunlight, and air-oxidation.

Hybrid thin traffic deck coating

Another new technology is a hybrid epoxy and polyurethane waterproofing system comprising a flexible polyurethane basecoat and epoxy topcoat. The basecoat provides the required flexibility and crack bridging while the topcoat is highly durable and resistant to abrasion and impact. This system also has a fast application and cure time.

It consists of a two-component polyurethane-based adhesive primer, a two-component fast-curing polyurethane basecoat, and a two-component fast-curing epoxy topcoat with limited movement capability and superior abrasion resistance.

Conclusion

Figures 1 (page 19) and 2 (page 20) provide a quick reference for the different waterproofing systems and their susceptibility to common problems, typical application times, relative installation costs, and anticipated service life. This should serve as a quick reference for designers and specifiers when determining an appropriate waterproofing system for a project. The development of new technologies has focused on addressing specific issues, but at this time, these technologies are limited to a very niche market as a result of limited suppliers and installers as well as a price point that is significantly higher than competitive systems.

Parking garages are designed to serve a wide variety of users and are either required for residents or designed to generate revenue for owners. There are many waterproofing systems available on the market, but it is important to know the suitability of each system and its limitations. Also note, all parking structure waterproofing systems must be designed by qualified engineers and installed by qualified applicators.

Installation of first ply and reinforcing for hot-rubberized waterproofing system.

An associate at RJC Engineers, James Cooper, P.Eng., LEED AP O+M, is responsible for managing projects from start to finish, including assessments, design, tendering, construction contract administration, and project close-out. Cooper has held multiple positions including project engineer at RJC Engineers since he joined the company in 2005 after graduating from the University of Toronto. He has more than 12 years of experience in the field of structural restoration and waterproofing, and has been involved in rehabilitation/retrofit projects throughout his career. A licensed professional engineer, Cooper is a member of the Professional Engineering Association of Ontario, and a Leadership in Energy and Environment Design (LEED) accredited professional with the specialty designation of Operation and Maintenance of existing buildings. He can be reached at jcooper@rjc.ca.

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CASE STUDY

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