RECLAMATION
Managing Water in the West

Technical Memorandum No. MERL-2013-55

Concrete Sealers Scoping Study
Science and Technology Project ID: 8262

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2013

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Materials Engineering and Research Laboratory, 86-68180

Technical Memorandum No. MERL-2013-55

Concrete Sealers Scoping Study
Science and Technology Project ID: 8262

9/19/13

Prepared by: Kurt F. von Fay,
Civil Engineer, Materials Engineering and Research Laboratory, 86-68180 | Date

9/19/13

Prepared by: Richard Pepin, PCS
Materials Engineering and Research Laboratory, 86-68180 | Date

9/19/13

Peer Reviewed by: Westin Joy, P.E.
MS, Civil Engineer, Materials Engineering and Research Laboratory, 86-68180 | Date

9/15/13

Noted: William F. Kepler, Ph.D., P.E.
Manager, Materials Engineering and Research Laboratory, 86-68180 | Date

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Materials Engineering and Research Laboratory
Denver, Colorado

May 2013

Contents

Introduction

The Materials Engineering and Research Laboratory conducted a scoping study on concrete sealers and coatings to review published information about their performance and methods to measure effectiveness. The study focused primarily on sealers and thin coatings that have the potential to penetrate fine cracks.

Background

Cracking in concrete is widely regarded as a long-term durability and maintenance problem. Cracks can allow ingress of moisture and other compounds into concrete, leading to further deterioration. Cracking is a problem that occurs in most geographical locations and climates, and in many types of concrete structures. Reclamation has a large inventory of aging concrete that is experiencing deterioration due to cracking.

Effective sealing and coating compounds could slow or halt deterioration in some cases. However, there is some confusion about which sealing and coating properties are the most effective and which tests are most relevant to review when choosing a product. Being able to select products that are the most likely to work based on their published material properties will help ensure that repairs are made as effectively as possible. In addition, following application requirements can have a large impact a product's performance.

Summary and Conclusions

There are several concrete sealing technologies that would be effective for reducing water infiltration on some of Reclamation's structures.

Depending on exposure conditions and anticipated use, silanes, siloxanes, high molecular weight methacrylates (HMWM) and low viscosity epoxies may be effective.

For applications using silanes, the newer formulations of gels and creams seem to be the most effective at achieving deeper penetration.

Several agencies have developed specifications and testing protocols for selecting sealers to protect concrete. In addition, several authors have evaluated different test methods for measuring sealer performance and have developed guidelines for their use.

Much of this published information can be used by Reclamation to develop a testing protocol and guide specifications for using these types of products on Reclamation infrastructure. Independent evaluation of these products has shown that manufacturers sometimes overstate product performance.

A small scale study should be conducted using the Reclamation protocol to compare our findings to those published by manufacturers and others.

DISCUSSION

There are wide varieties of compounds and exposure conditions that can degrade concrete. ACI Guide 515.2R-13 (ACI Committee 515, 2013) lists a number of concrete treatment options for various exposure conditions. The information provided is for general guidance only, and it does not make specific recommendations.

There are three basic classes of protective surface treatment that can be performed on concrete. The concrete surface can be treated with a coating that essentially covers the surface. These are typically polymeric materials such as epoxy, polyurethane or polyurea.

The surface can also be protected by low viscosity crack sealers, which can fill surface voids and cracks. These are typically low viscosity epoxies, high molecular weight methacrylates (HMWM), and urethanes.

The third general category is surface sealers, which saturate the surface with a penetrating water repellant compound which leaves the pores and cracks open, but repel water. Two types of surface sealing treatments are frequently used in the concrete industry. One type is a silane or siloxane based water repellant, both of which are based on silicon technology. The other type is a sodium silicate solution. Both types penetrate concrete pores and cracks and react with hydrated cement particles. In the case of silanes or siloxanes, they react to form a hydrophobic lining of the pores. The sodium silicates react to fill the pores with reactant products and function more as pore blockers. In some cases, this reaction may be damaging to concrete (Al-Otoom, Al-Khlaifa, & Shawaqfeh, 2007).

One of the main older technology treatments was the use of linseed oil. A study by the Missouri Department of Transportation (Wenzlick, 2007) determined that the linseed oil treatment that they had used for years was in many cases more effective than several newer technology sealers. They evaluated sealers using AASHTO T259, T529, and T277, and ASTM C672 and C642. However, many agencies have moved away from linseed oil as a treatment method.

Typically, surface sealants are applied by flooding the surface, spraying, rolling and/or squeegee. Crack sealing technologies can be applied by the same methods, and some are designed to be injected under low to high pressure into cracks. Costs related to pressure injection of cracks is typically significantly more than for other methods for crack sealing.

Silanes and related products have been receiving attention because of their potential effectives and ease of use. Unfortunately, tests results to measure the performance of sodium silicates is limited and they are likely only effective at shallow depths. A study of the effectiveness of various solvent based silanes and sodium silicates (Jian-Guo Dai, 2010) found that silane based gels and creams had the best penetration depths, followed by silane liquids. Sodium silicate penetration seemed to be only superficial (Jian-Guo Dai, 2010) (Christodoulou, Goodier, Austin, Glass, & Webb). In another study (Aitken & Litvin, 1989), a variety of sealers were tested on their ability to stop ingress of water and chlorides into concrete cubes. The only sealers that were observed to have penetrated the samples to a measureable depth were the silanes and siloxanes.

Penetration depth of hydrophobic sealers (silanes and siloxanes), pore blockers (silicates), and crack sealers can be very important to their performance. The major factors that affect their service life in most applications is surface abrasion, weathering and sunlight (ultraviolet radiation). Penetration depths in excess of 3 mm are typically recommended (Cady, 1994).

In addition, Dai found that for cracked concrete, treated cracks widths in excess of about 0.006 inches could not be sealed with silanes sufficiently to prevent ingress of chlorides. For cracks that formed after treatment, silanes were only effective for crack sizes of only 0.003 inches.

A survey of uses of HWMWs (Rahim A. , Jansen, Abo-Shadi, & Simek, 2010) found that they were used to treat cracks as small as 0.05 mm and up to about 12.7 mm. The study's authors recommended that cracks be treated as soon as practical after discovery, to prevent contamination from debris. They also recommended treating new concrete surfaces as soon as 3 months after construction.

It is important to note that there is confusion about the role of concrete cracking related to corrosion of rebar. ACI 222R-01 (reapproved in 2010) on page 14 states, "Cracks that follow the line of a reinforcing bar (as might be the case with a settlement crack) are much more damaging because the corroded length of the bar is greater and the resistance of the concrete to spalling is reduced." Studies have shown that cracks less than approximately 0.3 mm (0.012 in.) wide have little influence on the corrosion of reinforcing steel (Atimay & Ferguson, 1974). However, research (Darwin, Manning, & Hognestad, V 7, No 5, May 1985), (Oesterle, RD Serial No 2054, 1997) has shown that corrosion is not clearly correlated with surface crack widths, perhaps because there is poor correlation between surface crack openings and crack widths near rebar. ACI 318 states that although a number of studies have been conducted, clear experimental evidence is not available regarding the crack width beyond which corrosion danger exists. Exposure tests indicate that concrete quality, adequate consolidation, and proper concrete cover may be of greater importance for corrosion protection than crack width at the concrete surface.

Other investigations have shown that there is no relationship between crack width and corrosion (Beeby, 1978) (Tremper, 1947) (Martin & Schiessel, 1969), (Raphael & Shalon, 1971). One study (Beeby, Concrete in the Oceans—Cracking, 1978) showed that closely spaced cracks can actually cause greater corrosion rates than with more widely spaced, wider cracks. And in many cases, there is no direct relationship between surface crack width and the internal crack width. A detailed discussion relating to cracking is available in ACI 224R.

The reported effectiveness of using epoxy and HMWMs to seal cracks has been varied (Rahim & Jansen, 2006). A review of the published literature shows that clean cracks have the best chance for sealing using these products, as long as the cracks are of the appropriate size. Many studies have shown that dirt or debris in the cracks significantly reduced HMWM's ability to penetrate cracks. They have been used successfully in cracks ranging in size from 0.001 to 0.08 inches wide using gravity filling. In addition, the review showed that as long as there is sufficient penetration of the product into the cracks, most or all of the flexural strength of the concrete can be restored.

Pinchera & Dorshorst (2005) report results of crack sealing on the City Island Bridge deck for cracks ranging in width from 0.004 to 0.010 inches wide. Three HMWMs, one epoxy and one urethane resin were evaluated. The products were only able to penetrate to a maximum depth of 0.3 inches, which is not enough to rebond the cracks. The reason for the low penetration was attributed to dirt and debris in the cracks. Silanes were tested in another trial. Those were able to penetrate to a depth of about 2 inches. Even though they would not rebond the cracks, they would likely provide some protection against chloride ion penetration for smaller cracks.

In that same report, the authors ranked several concrete deck sealing products using a composite scoring system based on application characteristics, published material properties, user experiences, and several other factors. From that they selected several products to evaluate. Based on their findings, there was not good agreement between the composite score and actual performance, and none of the products evaluated appeared to penetrate into the concrete as deeply as the manufacturers claimed. Overall they found that solvent based silanes performed better than water born silanes or siloxanes.

For crack sealers, they found that the products evaluated generally worked well for cracks ranging from 0.06 inches to about 0.19 inches, and were capable of fully penetrating 3-inch deep cracks. However, the evaluated products did not work well to rebond cracks wider than that. Additionally, exposure to freezing and thawing weather seemed to reduce the performance of the crack sealers.

Some have shown that silanes or siloxanes and HMWM used in combination can be effective surface sealers (Attanayaka, Aktan, & Ng, 2002). For very small cracks (less than 0.002 inches), silanes were effective for screening chlorides. When cracks were between 0.002 and 0.08 inches, a combination of silane and HMWM was effective. They report that treating the surface with a silane, followed by treating the cracks with an HMWM should work.

In Christodoulou, Goodier, Austin, Glass, & Webb, the performance of silane treated concrete was evaluated using capillary absorption and water penetration tests. They were able to show that concrete treated as much as 20 years before the testing was still receiving some benefit from the silane treatment.

Testing Programs

Methods used to evaluate performance of deck and crack sealers are fairly straight forward, and can use chloride profile measurements as a result of chloride ponding (AASHTO T259/260), weight measurements to measure water absorption, and visual measurements (depth of penetration of a sealant, corrosion of rebar, etc.), among other methods.

AASHTO T259/260 is a test method to determine the resistance of concrete to chloride ion penetration. After specimen preparation, specimens are ponded with a deicing solution. At various time intervals, special techniques can be used to measure the chloride ion content at various locations within the test specimens. ASTM C1202 can also give an indication of permeability of concrete. However, with this test procedure, results can be misleading for some types of penetrating sealers (Pinchera & Dorshorst, 2005).

Bond strength of crack sealers is typically measured using a splitting tension test of cracked specimens glued together with a crack sealant. A more precise test method is the direct tension test, but it requires much more time for test specimen preparation.

Durability of surface sealers and crack sealers can be measured using a freezing and thawing test. Specimens can be treated, subjected to freezing and thawing cycles, then performance of the sealers can be evaluated.

Another important aspect is the actual depth of penetration of surface sealers in concrete. For these, test specimens can be split after treatment and sprayed or coated with some type of indicator. Water beading on the fractured surface may be enough to indicate depth of penetration. The Oklahoma Department of Transportation developed a test method using Solfonazo III and water to indicate depth of penetration by staining the untreated concrete (Oklahoma Department of Transportation, 2003).

In an attempt to ensure quality products are used on their structures, the Alberta Transportation Department developed a Specification for Concrete Sealers (Alberta Department of Transportation, 2009). The specification outlines test methods and performance requirements for sealers. As another example, the Minnesota Department of Transportation has published performance requirements and the corresponding test procedure for penetrating sealers used on their projects (Minnesota Department of Transportation, 2012).

The Oklahoma Department of Transportation (1999) has a guide specification of the use of HMWM and epoxies for the crack sealing of bridge decks (Oklahoma Department of Transportation, 1999). In that specification, they list the desired properties and associated test procedures for the crack sealants. They essentially treat the 2 materials as equivalent for the uses described in the specification. The specification also describes the necessary substrate preparation that needs to be completed before application of the sealer, including steps to try and clean the cracks of any debris.

The Kentucky Transportation Center examined several tests to establish evaluation criteria for concrete coatings (Palle & Hopwood, 2006). While their work was primarily focused on barrier type coatings, they identified five test procedures that should be used. They are AASHTO T259 and T260, ASTM D5894, ASTM D4541, ASTM E96, and ASTM D522.

The Rhode Island Department of Transportation developed their own protocol for evaluating concrete surface sealers (Road Island Department of Transportation Materials Laboratory). Their evaluation criteria look at chloride ion intrusion screening, water absorption and water vapor transmission, and freezing and thawing durability. Their protocol describes test methods and reporting criteria, but does not list passing or failing test requirements.

In (Attanayaka, Aktan, & Ng, 2002), they used criteria listed in NCHRP Report 244 (Series II) Test procedure (Pfiefer & Scali, 1981) and Alberta DOT test BT 001 (Alberta Department of Transportation, July, 2000) to evaluate surface sealers. They present a table of factors to consider and a flow chart to use to assist in the selection of an appropriate sealer. Further, they reported that low modulus HMWMs were more effective at treating cracks long term than high modulus HMWMs. They also found that depth of penetration of sealers was typically overstated by manufacturers. For new concrete, it should be at least 28 days old before application. For concrete that is more than one year old, the entire surface will need to be sand blasted or high pressure water jetted before application of a sealer to remove the carbonated layer and to remove any other contaminants.

In the Missouri DOT study (Wenzlick, 2007) they developed a draft special provision to allow for the use of sealers other than linseed oil which listed test procedures to be used for evaluation and allowable values. They also described surface preparation methods that should be performed before application of a sealer.

Bibliography

ACI Committee 515. (2013). *Guide to Selecting Protective Treatments for Concrete, ACI 515.2R-13.* Farmington Hills: American Concrete Institute .

Aitken, C. T., & Litvin, G. G. (1989, November). Laboratory Investigation of Concrete Sealers. *Concrete International: Design and Construction, Vol 11, No 11* , pp. 37-42.

Alberta Department of Transportation. (2009). *Specification for Concrete Sealers, B388.* Alberta: Alberta DOT.

Alberta Department of Transportation. (July, 2000). *Test Procedure for Measuring the Vapour Transmission, Waterproofing and Hiding Power of Concrete Sealers BT001.* Alberta DOT.

Al-Otoom, A., Al-Khlaifa, A., & Shawaqfeh, A. (2007). Crystallization Technology for Reducing Water Permeability into Concrete. *Ind. Eng. Res. , American Chemical Society* , 5463-5467.

Atimay, E., & Ferguson, P. (1974). Early Chloride Corrosion of Reinforced Concrete - A Test Report. *Materials Performance, Vol 13, No 12* , 18-21.

Attanayaka, U., Aktan, H., & Ng, S. (2002). *Criteria and Benefits of Penetrating Sealants for Concrete Bridge Decks, Research Report RC-1424.* Lansing: Michigan Department of Transportation.

Beeby, A. W. (1978). *Concrete in the Oceans—Cracking.* Department of Energy, London: CIRIA/UEG, Construction Industry Research and Information Association.

Beeby, A. W. (1978, June V. 56A, No. 3). Corrosion of Reinforcing Steel in Concrete. *The Structural Engineer* , pp. 77-81.

Cady, P. (1994). *NCHRP Report 209: Sealers for Portland Cement Concrete Highway Facilities.* Washington, DC: Transportation Research Board, National Research Council.

Christodoulou, C., Goodier, C., Austin, S., Glass, G., & Webb, J. (n.d.). Assessing the Long-Term Durability of Silanes on Reinforced Concrete Structures. *AECOm Europe, 94-96.*

Darwin, D., Manning, D., & Hognestad, E. (V 7, No 5, May 1985). Debate:Crack Width, Cover, and Corrosion. *Concrete International* , 20-35.

Jian-Guo Dai, Y. A. (2010). Water Repellent Surface Impregnation for Extension of Service Life of Reinforced Concrete Structures in Marine Environments: The Role of Cracks. *Cement and Concrete Composites* , 101-109.

Martin, H., & Schiessel, P. (1969). The Influence of Cracks on the Corrosion of Steel in Concrete. *Preliminary Report, RILEM International Symposium on the Durability of Concrete.*

Prague.

Minnesota Department of Transportation. (2009). *Mn/DOT Bridge Penetrating Sealer Qualification Procedure.* Maplewood: MnDOT.

Minnesota Department of Transportation. (2012). *MnDOT Bridge Penetrating Sealer Qualification Procedure.* Maplewood: MnDOT.

Oesterle, R. (RD Serial No 2054, 1997). *The Role of Concrete Cover, in Crack Control Criteria and Corrosion Protection.* Skokie: Portland Cement Association.

Oklahoma Department of Transportation. (1999). *Special Provisions for Concrete Surface Repair by Sealing, 523-1 (a-f) 99, 08-03-04.* Oklahoma Department of Transportation.

Oklahoma Department of Transportation. (2003). *Method of Core Test For Determining Depth of Penetration of Penetrating Water Repellant Treatment Solution into Portland Cement Concrete, OHD L-40.* Oklahoma City: Oklahoma State.

Palle, S., & Hopwood, T. (2006). *Coatings, Sealants and Fillers to Address Bridge Concrete Deterioration and Aesthetics-Phase 1.* Lexington: Kentucky Transportation Center, University of Kentucky .

Pfiefer, D., & Scali, M. (1981). *"Concrete Sealers for Protection of Bridge Structures".* Transportation Research Board, Washington: National Research Council.

Pinchera, J. A., & Dorshorst, M. A. (2005). *Evaluation of Concrete Deck and Crack Sealers.* Madison: Wisconsin Department of Transportation.

Rahim, A., & Jansen, D. (2006). *Concrete Bridge Deck Crack Sealing: An Overview of Research.* Sacramento: California Polytechnic State University.

Rahim, A., Jansen, D., Abo-Shadi, N., & Simek, J. (2010). Overview of High Molecular Weight Methacrylate for Sealing Cracks in Concrete Bridge Decks. *Journal of the Transportation Research Board, No 2002* , 77-81.

Raphael, M., & Shalon, R. (1971). A Study of the Influence of Climate on Corrosion of Reinforcement. *RILEM Symposium on Concrete and Reinforced Concrete in Hot Countries, Building Research Station*, (pp. 77-96). Haifa.

Road Island Department of Transportation Materials Laboratory. *Evaluation of Concrete Surface Sealers.* RIDOT.

Tremper, B. (1947). The Corrosion of Reinforcing Steel in Cracked Concrete. *ACI JOURNAL, Proceedings V. 43, No.* (pp. 1137-1144). ACI.

Wenzlick, J. (2007). *Bridge Deck Concrete Sealers, OR07-009.* Jefferson City: Missouri Department of Transportation.