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Comparison of the Bonding Characteristics and Corrosion Resistance between Warren Environmental epoxy, Spectrashield, Spraywall, and Specialty Concrete Lining Systems

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COMPARISON OF THE BONDING CHARACTERISTICS AND CORROSION RESISTANCE BETWEEN WARREN ENVIRONMENTAL EPOXY, SPECTRASHIELD, SPRAYWALL, AND SPECIALTY CONCRETE LINING SYSTEMS

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May 2009

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STATEMENT OF LIMITATION

The conclusions presented in this report are based on the services described and not on tasks or procedures beyond the scope of the described procedures or the time and budgetary constraints imposed by the contract limitations.

Rust Solutions, Inc. has performed this comparison in a professional manner using that degree of skill and care exercised for similar projects under similar conditions by reputable and competent consultants, and in accordance with the procedures established within Rust Solution's quality assurance, quality control protocol.

Rust Solutions, Inc. shall not be responsible for conditions or consequences arising from relevant facts that were concealed, withheld or not fully disclosed at the time the work was performed.

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SUPPORTING DATA ATTACHMENTS

1. Evaluation of Protective Coatings for Concrete performed by the County Sanitation Districts of Los Angeles County, Whittier California. Final Report December, 2004. (Redner Report): by John A. Redner, Sewage Departmental Engineer, Randolph P. His, Associate Engineer, Edward J. Estefandi, Senior Engineer, Roger Sidney, Civil Engineer, Robin M. Jones, Associate Engineer, Donna Won, Senior Engineer, James Andraska, Supervising Civil Engineer.

2. Testing Warren Environmental, Inc. Product for use in Coating Wastewater Concrete, Clay Brick Facilities. Testing as performed in the Laboratory of the Center for Innovative Grouting Materials and Technology (CIGMAT) Department of Civil Environmental Engineering: by C. Vipulanandan, Ph D., P.E. and J. Liu, Ph D. December, 2004.

3. Evaluating CCI Spectrum, Inc. Product for Coating Wastewater Concrete and Clay Brick Facilities in the City of Huston. Coating Material Spectrashield Liner System; Testing as performed in the Laboratory of the Center for Innovative Grouting Materials and Technology (CIGMAT) Department of Civil Environmental Engineering: by C. Vipulanandan, Ph D., P.E. and J. Liu, Ph D December, 1996.

Abstract

Between June and Dec, 2009 Rust Solutions Inc. conducted an unbiased review of data from independent testing laboratories, manufacturer printed data and coating generic type performance and behavior data in order to compare the bonding characteristics and corrosion resistance of Warren Environmental Epoxy, Spectra Shield, SprayWall, Thorotop HCR, Thoroseal, Thoro Polymer Concrete, All Crete MP, Swindress Bond 110, Acid Proof Cement No. 54, and Hortoncrete 126-6200 .

The performance of the coating systems is based the following test results:

- Evaluation of Protective Coatings for Concrete performed by the County Sanitation Districts of Los Angeles County, Whittier California. Final Report December, 2004. (Redner Report): by John A. Redner, Sewage Departmental Engineer, Randolph P. His, Associate Engineer, Edward J. Estefandi, Senior Engineer, Roger Sidney, Civil Engineer, Robin M. Jones, Associate Engineer, Donna Won, Senior Engineer, James Andraska, Supervising Civil Engineer.

- Testing Warren Environmental, Inc. Product for use in Coating Wastewater Concrete, Clay Brick Facilities. Testing as performed in the Laboratory of the Center for Innovative Grouting Materials and Technology (CIGMAT) Department of Civil Environmental Engineering: by C. Vipulanandan, Ph D., P.E. and J. Liu, Ph D. December, 2004.

- Evaluating CCI Spectrum, Inc. Product for Coating Wastewater Concrete and Clay Brick Facilities in the City of Huston. Coating Material Spectrashield Liner System; Testing as performed in the Laboratory of the Center for Innovative Grouting Materials and Technology (CIGMAT) Department of Civil Environmental Engineering: by C. Vipulanandan, Ph D., P.E. and J. Liu, Ph D December. 1996.

The Warren Environmental epoxy systems as well as the Spraywall and the following specialty concrete products, Thorotop HCR, Thoroseal, Thoro Polymer Concrete, All Crete MP, Swindress Bond 110, Acid Proof Cement No. 54, and Hortoncrete 126-6200s participated in the County Sanitation Districts of Los Angeles County Study .

The coatings were evaluated on a scale of 1-4 in each of the categories of ease of application, acid resistance, and concrete bonding. A total score of 6 or a score of 3 or more in any of the categories was considered a failure, the lower the score the better the product performed.

The Redner Study testing results indicate that the Warren Environmental product outperformed all the other products as presented in this report.

- The Warren product (code C-89 on the Redner Report) received a final score of **4**.
- The Spraywall product (code C-92 on the Redner Report) received a total score of **5**.
- All specialty concrete products as identified above, **failed**.

The adhesion test results as reported CIGMAT from the Warren Environmental and

Spectrashield independent reports indicate:

Dry Concrete
Warren Environmental no coating failure.
Spectrashield coating failed in direct tension.

Wet Concrete
Warren Environmental no coating failure.
Spectrashield coating failed in direct tension. Bonding strength of primer with wet concrete was good, poor coating (4 layer system) strength.

Dry Brick
Warren Environmental no coating failure.
Spectrashield coating failed in direct tension. Bonding strength of primer with wet concrete was good, poor coating (4 layer system) strength

Wet Brick
Warren Environmental no coating failure.
Spectrashield coating failed in direct tension. Bonding strength of primer with wet concrete was good, poor coating (4 layer system) strength

CIGMAT test results indicate that Warren Environmental surpasses Spectrashield in adhesion performance in accordance with ASTM 4541.

CIGMAT tested both systems, the Warren Environmental and Spectrashield to a Full Scale Hydrostatic Test. The test was performed to evaluate the potential of applying the Warren Environmental and Spectrashield products on a wet surface under a hydrostatic water back pressure. The test was performed and the results are:

Warren Environmental S-301 passed.
Spectrashield passed.

- The summary of the Redner tests results revealed that the Warren Environmental system's general test scores are superior to those of the Spraywall system.
- The summary of the CIGMAT test results indicate that the Warren Environmental system exhibits superior bonding to dry and wet concrete and superior bonding to dry and wet brick than the Spectrashield system. Spraywall did not participate in the CIGMAT study.
- The Warren Environmental system's Hydrostatic Test duration was longer than the Spectrashield test.
- The Warren Environmental system passed both the Redner Study and CIGMAT Sulfuric Acid Resistance Tests.
- The Spraywall system passed the Redner Sulfuric Acid Resistance Test.

- The Spectrashield system passed the CIGMAT Sulfuric Acid Resistance Test.

The adhesion issues as reported in the Spraywall and Spectrashield product testing are typical of fast drying coatings relaying on a thin primer layer for adhesion. Fast drying coatings do not have the wetting properties to penetrate the concrete capillary pores to provide adequate bond, especially if moisture is present. Polyurethane and polyurea hybrids are typically known as hydrophobic resins (sensitive to moisture).

(1) Penetration is to concrete what surface profile is to steel. In both cases, maximum adhesion is the goal. Coatings that penetrate concrete have much improved adhesion and increased long-time performance as compared to those that remain on the surface and rely on adhesion alone.

Optimum adhesion is imperative. (2) Any products' physical properties and performance are directly impacted by the quality of its adhesion to the concrete substrate. A good adhesion capability must be included in any material selection criteria.

(3) In addition to adhesion, the coating needs to have appreciable thickness and be physically strong in order to resist the back pressure of the water. If it did not have this property, it would not be satisfactory for any area where water pressure can develop within the concrete and underneath the coating.

The limitations of lining application as reviewed on Spectrashield's printed manufacturer's specifications are that the invert of the manhole is not lined; furthermore, no detail of watertight coating application to the upstream and downstream pipe/manhole interface was identified. Water will follow the path of least resistance. If the invert is not lined the potential for infiltration will remain.

No field quality control requirements for vacuum testing are specified by Spectrashiel. No quantifiable data can be obtained without tightness testing as required by ASTM C1244

Adhesion anomalies were reported on Spectrashield and Spraywall. Adhesion anomalies can increase the risk of microbial colonization between the concrete and the coating, potentially creating a corrosive environment, increasing the probabilities of cement paste loss and structural damage of the host structure; poor adhesion of a coating system has a direct impact on the ability to eliminate infiltration of ground water into the structures being lined. Poor adhesion equals poor infiltration properties.

Introduction

The services of Rust Solutions Inc. were retained by Metropolitan Wastewater Reclamation District to provide professional corrosion engineering services. The task consisted review of the data contained in three reports and manufacturer's specification data sheets, application requirements and behavior of generic liquid coating systems as related to 100% solids thixotropic epoxy, 100% solids polyurethane, 100% solids silicone modified polyurea and specialty concrete lining systems for the protection and rehabilitation of wastewater infrastructure exposed to corrosive H_2S and H_2SO_4.

The purpose of this task is to compile the data as reported by the Redner and CIGMAT reports and information as published by manufacturers. This report serves as a comparison of bonding characteristics and corrosion resistance of Warren Environmental Epoxy to Spectrashield Polyurethane, Spraywall Silicone Polyurea Hybrid and Specialty Concrete Lining Systems.

The comparison data presented in this report is vital for the specifying engineer or facility owner; the data provides clear and concise information supported by industry standards and recommended practices for the protection and rehabilitation of sewage treatment and transport infrastructure.

Because of government mandated industrial pretreatment, longer detention times for waste water due to construction of regional treatment plants, strict air quality regulations and other factors, concrete structures in waste water transport and treatment plants are exposed to more severe exposure conditions now more than in the past. These changes coupled with dwindling budgets have created an environment in which any investment must meet or exceed its intended return. Selecting the proper material for new infrastructure or rehabilitation is crucial.

To meet criteria of corrosion protection, infiltration mitigation and a fifty year useful service life, the specifying engineer must have a clear understanding of and supporting data for the material to be considered for the project. Once the performance and historical data is evaluated, a performance specification can be developed to provide a level playing field, thus insuring a good investment for many years to come.

In addition to corrosion mitigation, the purpose of lining manholes is to eliminate manhole infiltration into the conveyance system. Manhole infiltration to conveyance systems has been reported to account for up to 25% of the total infiltration, thus increasing the treatment cost.

Last but not least, qualified inspection by NACE, International Certified Coatings Inspectors has proven to be an effective approach to assure the contract specifications are being met and the work is being performed in strict accordance the contract documents. It is a well documented fact that utilizing NACE Certified Coatings Inspectors has an enormous positive impact in the quality of the work, assuring maximum service life.

Literature Review

The data reported in the CIGMAT and Redner reports clearly indicates and quantifies the adhesion performance and chemical resistance of the coating systems. The quantifiable data in addition to supporting information from the sources listed below clearly depict the strengths and weakness of the coatings being compared.

This study is limited to the laboratory information presented; further analyses should be performed on the coating systems being evaluated on applications performed to correlate historical data of long term real world performance (5 and 10 year history)

Test result information was obtained from:

- Evaluation of Protective Coatings for Concrete performed by the County Sanitation Districts of Los Angeles County, Whittier California. Final Report December, 2004. (Redner Report): by John A. Redner, Sewage Departmental Engineer, Randolph P. His, Associate Engineer, Edward J. Estefandi, Senior Engineer, Roger Sidney, Civil Engineer, Robin M. Jones, Associate Engineer, Donna Won, Senior Engineer, James Andraska, Supervising Civil Engineer.

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- Evaluating CCI Spectrum, Inc. Product for Coating Wastewater Concrete and Clay Brick Facilities in the City of Huston. Coating Material Spectrashield Liner System; Testing as performed in the Laboratory of the Center for Innovative Grouting Materials and Technology (CIGMAT) Department of Civil Environmental Engineering: by C. Vipulanandan, Ph D., P.E. and J. Liu, Ph D December. 1996.

Research Supporting Information:

- Existing Sewer Evaluation & Rehabilitation Second Edition WEF Manual of Practice FD-6 ASCE Manual and Report on Engineering Practice No. 62 Published by Water Environment Federation and the American Society of Civil Engineers.

- Corrosion Prevention by Protective Coatings Second Edition, by Charles G. Munger, Revised by Louis D. Vincent, PhD.

- Concrete Repair Manual Third Edition, Vol. 1 & 2 by American Concrete Institute and International Concrete Repair Institute

- EPA (WH-547) Hydrogen Sulfide Corrosion in Wastewater Collection and Treatment Systems. Report to Congress by the Environmental Protection Agency

- Paper No. 379 Corrosion 97 Future Material Selection Guidelines for Coatings on Concrete for Changing Exposures conditions in Large Municipal Wastewater Collection / Treatment Systems by Randy Nixon.

- Spraywall specification data sheet by Sprayroq.

- Spectrashield Liner System Technical Data. (www.spectrashield.com/tdata.htm)

Methodology

Redner Report:

Corrosion Testing Facility

This summary states the testing protocol to evaluate protective coatings for application to corroded concrete. The accelerated corrosion tests were performed simulating actual application conditions. The testing was conducted by the County Sanitation District of Los Angeles County, California. The testing was conducted at the District's Compton Field Office in the city of Compton, California. The program started in 1983 and ended in 2004.

The evaluations were conducted in shallow concrete tanks constructed by inserting two concentric, precast reinforced concrete manhole shafts into a freshly poured, wet concrete base slab. The inner tank diameter was 0.9 m (3 ft.) with a depth of approximately 0.8 m (2.5 ft.). The outer tanks were constructed of type II Portland cement manufactured to meet or exceed the requirements of ASTM C 478. The annular space between the outer and inner tank was filled with water to simulate moisture from groundwater.

Evaluation Procedure

The lower half of each tank was allowed to corrode for six to eight weeks using 265 liters (70 gallons) of 10% (by weight) solution of sulfuric acid. Approximately 25 mm (1 in.) of corrosion was observed to occur in the unprotected concrete tanks during this period. This rate of corrosion is fifteen to twenty times the highest corrosion rate expected in actual service. The use of 10% acid was arbitrary, but it represents a more corrosive environment than the actual service situation.

A coating application to the test tank was scheduled when sufficient aggregate and even some reinforcing steel had been exposed. The manufacturer was requested to apply the coating to both the corroded and uncorroded surfaces inside the tank. The coating manufacturer was responsible for all surface preparation prior to application of the coating. Generally, the manufacturers chose either sandblasting or high-pressure water blasting for surface preparation. If too much aggregate was exposed for proper application of the coating, then the manufacturer was responsible for surface repairs as well. Most surface repairs used fast curing cement or a mixture of the coating material with an inert filler such as sand. The entire application process, including surface preparation, had to be completed within 8 hours.

The coating to be tested had to be able to cure sufficiently so that water could be added to the test tank within 48 hours after application. A total of 96 hours after the application of the coating, sufficient concentrated sulfuric acid was added to the water in the test tank for final acid concentration of 10% by weight. The acid level in the coated test tank was set high enough to also submerge a portion of the uncoated concrete.

The test procedure had been designed to simulate the application of coatings to manholes or pipelines and then return to corrosive conditions. Coating systems that require longer application or cure times are less attractive for most rehabilitation projects, but are still considered for new construction.

The manufacturers were not permitted to perform any pinhole or holiday testing after the application of the coating, even though such testing is used as part of standard application specification. The existence of coating or application flaws was often apparent and after the application was obvious during the test phase. A coating system that cannot be applied without pinholes or holidays on such a small scale by the manufacturer was not considered.

The objective of the test was to evaluate the coating's application requirements, concrete bonding characteristics, and acid resistance for a minimum of one year of acid service. Unless coating failure was observe earlier, the acid solution was usually removed on a quarterly or semiannual basis to allow a physical inspection of the test tank. During the inspection, photographs were taken to document any changes in the coating's appearance. Observations were made of the coating's bonding characteristics and measurements were made of the coating thickness. A cross section of the coating was inspected to evaluate pinholes, air pockets or any gradual deterioration or reaction with the acid. The manufacturers were given the opportunity to repair any damaged areas that were noted in the inspection.

It is important to consider some of the limitations of this evaluation and the testing procedure. The effects of long term aging, exposure to moisture and bacterial action were not evaluated. This testing procedure is believed, however, to adequately evaluate the ability of a coating system to be effectively applied and to resist extensive sulfuric acid exposure. The continuation of testing beyond the one year acid service goal, for the successful coating systems, was occasionally done to obtain additional information on long term performance. It should be noted that some of the coatings that successfully passed this test later failed in actual sewer application. The failures may have been due to permeability of the coating to hydrogen sulfide gas, which this testing procedure did not address.

CIGMAT Report:

The objective of this study was to evaluate the coating systems (dry and wet) for use in sewer rehabilitation projects. Specific objectives are as follows: (a) to evaluate the application and performance of coatings on concrete under hydrostatic pressure of 15 psi (32 ft of water); (b) to evaluate the acid resistance of the coated concrete and clay bricks with and without holidays; and (c) to determine the bonding strength of the coating materials to concrete and clay bricks over a period of time.

Materials and Testing Program

WARREN ENVIRONMENTAL S-301; It is a 100% solid epoxy. The coating was applied after water jet blasting the surface. The coating was white in color. Application temperature was 65^{o}F. The coating was applied to the concrete pipe wet condition after several months of saturation in the test chamber. No primer was used before coating.

SPECTRASHIELD LINER; It is a skin panel system composed of epoxy primer, moisture barrier (modified polymer), surfaces (polyurethane/polymeric blend foam) and final barrier coat (modified polymer) (as per CCI Spectrum, Inc. literature). The system was applied in four-steps and the total thickness was about 1mm (3/4 inch). The epoxy primer was 100% solid. The coating was applied after water jet blasting the surface. The coating was pink in color. Application temperature was 65^{o}F. The coating was applied to the concrete pipe after one month of saturation in the test chamber.

Testing Program

Full Scale Test

The coatings can be applied to a dry or wet concrete surface. Dry coating condition simulates the new concrete surface while the wet condition simulated the rehabilitation condition. The coating applicators were allowed to select the conditions for application of their coating materials.

Hydrostatic Pressure Test: In order to stimulate hydrostatic back pressure on concrete structures due to the water table, it was decided to use concentrically placed concrete pipes to develop the necessary full-scale testing conditions. This was achieved by using 900 mm inner pipes and 1600 mm outer pipes with two concrete end plates. Steel elements were used to support the entire set-up. Inner concrete pipes were representing a concrete surface under hydrostatic pressure and coating a pipe surface represented most of the difficult conditions encountered in coating structures such as lift stations. The total area available for coating was 14 sq. meter (150 sq. ft.). Based on federal regulations, 900 mm (36in.) diameter pipe was the smallest pipe in which a coating applicator can be allowed to operate within the concrete pipe. Pressure chamber used for the full scale test was designed and built by Gifford-Hill & Company, Houston Division, which was representing the American Concrete Pipe Association.

Dry test (SPECTRASHIELD LINER) Coating was applied to a new 900 mm diameter concrete pipe at the Gifford-Hill & Company concrete pipe yard in Houston. The coated pipe was then placed in the pressure chamber for hydrostatic pressure testing.

Wet Test: (WARREN ENVIRONMENTAL S-301 AND SPECTRASHIELD LINER**)** The 900 mm (36-inch) concrete pipe was installed in the Test chamber and pressurized at 105kPa (15psi) for at least two weeks before applying the coating.

Measurements

Visual Inspection: The coated surfaces were visually inspected regularly and blistering, spalling, discoloring and cracking were noted and photographed. ASTM D 714-87 was used to characterize the blister size and frequency which are designated as dense, medium dense, medium or few accordingly.

Bonding Test (ASTM D 4541-85): In situ bonding tests on the coating materials were performed at the end of the hydrostatic test. A 51 mm (2 in.) diameter core drill was used to core into the concrete surface and isolate the test area and a metal piece was glued to the coating with an epoxy. After 24 hrs of curing, the test was performed using a hydraulic loading system to determine the bonding strength and the type of failure.

Laboratory Test

Holiday Test – Chemical Resistance (Modified ASTM G 20-88)

In order to study the chemical resistance, a ASTM G 20-88 test was modified to use with concrete and clay brick materials. As shown in Fig. 2 the specimens are immersed in a selected test reagent to half the specimen height in a closed bottle so that the specimens are exposed to the liquid phase and vapor phase. This method is intended for use as a relatively rapid test to evaluate the acidic resistance of coated specimens under anticipated service conditions. In this test, 76 mm (3-inch) X 152 mm (6-inch) cylindrical cement concrete specimens were used. Specimens were prepared by striping the molds from the concrete cylinders leaving the base in place. Clay bricks were cut to a size of 50 mm (2 inch) X 38 mm (1.5 inch) X 152 mm (6-inch) for this test. Dry and wet specimens were coated on all sides except the base (only for concrete) and tested. For the test two radial holes were drilled into the specimen approximately 15 mm deep (Fig. 3). In this test the changes in (1) amount of calcium leached into the test medium (2) weight of specimen (3) appearance of specimen and (4) pulse velocity (ASTM C 597-83) of the specimen were measured at regular intervals. The three reagents selected for this study are (1) deionized (DI) water (pH= 5 to 6) (2) 3% sulfuric acid solution (pH = 0.45; representing the worst reported condition in the wastewater system) and (3) 30% sulfuric acid solution (pH = -0.8; representing accelerated testing conditions) were selected for testing the coated materials. Control tests were performed with no holidays. Over **60** specimens were tested for Warren S-301 and over **30** specimens were tested for Spectrashield coating material.

Bonding Strength

These tests were performed to determine the bonding strength (pull-off strength) between The concrete/clay brick and the coating material over a period of one year.

ASTM C 321-94: In this test the coating was sandwiched between a pair of rectangular concrete blocks and clay brick specimens and then tested for bonding strength. Both dry and wet specimens were used to stimulate the extreme coating conditions. The bonded specimens were cured under water up to the point of testing. Total of **14** tests were performed on Warren Environmental S-301 and **12** tests were performed on Spectrashield during the period covered in this report.

ASTM D 4541-85: In this test a 51mm (2-in) diameter circular area was used for testing. Coated concrete blocks and clay bricks were cored using a diamond core drill to predetermined depth to isolate the coating and a metal fixture was glued to the isolated coating section using a rapid setting epoxy. Total of **28** tests were performed on Warren Environmental S-301 and **12** tests were performed on Spectrashield during the period covered in this report.

Results

The Warren Environmental epoxy systems as well as the Spraywall and the following specialty concrete products Thorotop HCR, Thoroseal, Thoro Polymer Concrete, All Crete MP, Swindress Bond 110, Acid Proof Cement No. 54, and Hortoncrete 126-6200s participated in the County Sanitation Districts of Los Angeles County Study.

The coatings were evaluated on a scale of 1-4 in each of the categories of ease of application, acid resistance, and concrete bonding. A total score of 6 or a score of 3 or more in any of the categories was considered a failure, the lower the score the better the product performed.

Application Data- Protective Coatings Systems Evaluated

Code No.	Surface Preparation 1	Surface Repair	Primer	Application Method	Coating Thickness Tank Wall mm (mils)	Coating Thickness Tank Base mm(mils)
C-89	SB, WB	No	Yes	Trowel & Spray	15.2 (600)	25.4 (1000)
C-92	CH, WB	Yes [2]	No	Spray	7.6 (300)	7.6 (300)

Notes:
1. Surface preparation letter designation: CH - chipping hammer; G - mechanical grind; R - water rinse; SB - sandblast; WRB - wirebrush; and WB - water blast.
2. Fast cure mortar.

Test Results for Protective Coating Systems Evaluated.

Code No.	Exposure Time (Days)	Applica-tion	Acid Resistance	Concrete Bond	Total Score	Comments
C-89	365	1	2	1	4	Slight discoloration.
C-92	370	1	2	2	5	Variable bond. Shallow pinholes but no acid penetration

Explanation of Rating System:
1. No application problems; excellent resistance to acid; and good bond to concrete
2. Some application problems that are attributed to the applicator and not a reflection of a coating material problem; some reaction with the acid, such as a color change or surface sheen change, but no coating failure; and an adequate, but not necessarily tenacious, bond to the concrete substrate. None of these problems are judged to be significant during the evaluation.
3. Significant problems developed during the application or during the evaluation phase; the material did not bond adequately to the concrete, indicating that the coating could not reliably protect the concrete.

4. A failure in the coating system as a result of serious application problems; a reaction of the acid with the coating; or failure of the coating to protect the concrete during the evaluation period.
N/E: Not evaluated due to early failure in other categories.
N/A: This category is not applicable to the particular product being tested.
Failed: A total score of "Failed" is assigned to those products that either received a total score of 6 or greater, and/or received a score of 3 or 4 in any of the categories.

- The Warren product (code C-89 on the Redner Report) received a final score of **4**.
- The Spraywall product (code C-92 on the Redner Report) received a total score of **5**.
- All specialty concrete products as identified above, **failed**.

The Redner Study testing results indicate that the Warren Environmental product scored superior performance results than all the other products as presented in this report.

The following adhesion test results were taken from the Center of Innovative Grouting Materials and Technologies (CIGMAT) reports from the Warren Environmental and Spectrashield System testing. The test results as included herein are specific to evaluate bonding strength in both Dry and Wet conditions on concrete and brick surfaces and coating behavior under hydrostatic pressure. Spraywall did not participate in the CIGMAT study.

Both systems were subjected to adhesion testing in accordance with ASTM 4541-85. The test results as reported were:

Dry Concrete

- Warren Environmental no coating failure, average bond strength **322 PSI**
- Spectrashield coating failed in direct tension, average bond strength **71 PSI**

Wet Concrete

- Warren Environmental no coating failure, average bond strength **434 PSI**
- Spectrashield coating failed in direct tension, average bond strength **51 PSI.** Bonding strength of primer with wet concrete was good, poor coating (4 layer system) strength.

Dry Brick

- Warren Environmental no coating failure, average bond strength **231 PSI**
- Spectrashield coating failed in direct tension, average bond strength **107 PSI**. Bonding strength of primer with wet concrete was good, poor coating (4 layer system) strength

Wet Brick

- Warren Environmental no coating failure, average bond strength **241 PSI**
- Spectrashield coating failed in direct tension, average bond strength **59 PSI**. Bonding strength of primer with wet concrete was good, poor coating (4 layer system) strength

CIGMAT test results indicate that Warren Environmental surpassed Spectrashield in adhesion performance in accordance with ASTM 4541.

Both systems Warren Environmental and Spectrashield were subjected a Full Scale Hydrostatic Test. The test was performed to evaluate the potential of applying the Warren Environmental and

Spectrashield on wet surface under a hydrostatic water back pressure of 15 psi (equivalent to 32 ft. of water), the test was performed and the results were:

- Warren Environmental S-301 coating was applied successfully under hydrostatic test conditions and tested for a period of **eight months**, the test **passed**.

- Spectrashield coating was applied successfully under hydrostatic test conditions and tested for a period of **five months**, the test **passed**.

Discussion

Based on the comparison of the bonding characteristics and corrosion resistance of Warren Environmental Epoxy to Spectrashield, Spraywall and Specialty Concrete Lining Systems to provide adequate **in service** performance in wastewater conveyance and treatment systems the results for adhesion and chemical resistance as per the Redner and CIGMAT reports indicate:

Adhesion

Good adhesion is essential for the long term success with any liner system that is subject to high H_2S levels and hydrostatic pressure.

- Warren Environmental epoxy's adhesion results were superior to those of Spectrashield, Spraywall and Specialty Concrete Lining Systems.

- Spectrashield and Spraywall products' lower adhesion values can be attributed to the wetting properties of the rapid drying coating systems. In addition to poor wetting properties, both coating generic types tend to be hydrophobic, thus enhancing the lack of adhesion properties. Poor adhesion of a coating system has a direct impact in the ability to eliminate infiltration of ground water into the structures being lined. Poor adhesion equals poor infiltration properties.

- Specialty Concrete Lining Systems failed.

The importance of adhesion of coatings and/ or linings utilized for the corrosion protection of wastewater conveyance and treatment systems is imperative. [4] The bond between the coating and concrete substrate should remain intact. Even with proper surface preparation, the bond can break down. If the coating is highly impermeable to water vapor, water may condense at the concrete-coating interface and destroy the bond.

Another adhesion issue to consider while utilizing Spectrashield and Spraywall is capillary pressure, due to the material temperature and moisture saturated substrate.

[5] Capillary flow can be described as the ability of a liquid to wet surface. The wetting of the surface is directly related to the surface tension of the liquid. The lower the surface tension, the greater the capillary flow. The principal of capillary can be demonstrated using a drop of ink and

paper towel. Touch the surface of the ink with the edge of the towel and watch the ink climb up hill. This affects the concrete and the coatings because concrete is a matrix of sand, cement, stone and air pockets. Water or other similar low surface tension fluids will "wick" their way through the capillaries in the concrete matrix. The rate at which this happens will depend at least or partially on the size of the capillary passages, surface tension of the fluid and temperature differentials.

Corrosion resistance

Concrete is an age old structural material that has been used in one form or another since the time of the Romans, some 2000+ years ago. Concrete has many advantageous properties, including low cost; a distinct disadvantage sometimes is its poor durability. Examples of durability problems in wastewater systems are due to the presence of hydrogen sulfide.

Increased corrosion rates of sewage conveyance and treatment are attributed to the effects of industrial pretreatment, retention time, longer transport distances, turbulence, etc. Hydrogen sulfide corrosion may result from two mechanisms:

(1) Acid attack resulting from the biological conversion of hydrogen sulfide gas to sulfuric acid in the presence of moisture.
(2) The direct attack on metals such as copper, iron, and steel by hydrogen sulfide gas.

The first mechanism is responsible for corrosion of sewers and structures used in the conveyance and treatment of sewage. The second mechanism is generally responsible for corrosion of electrical contacts, copper pipe, and other metallic components in pumping stations, lift stations, and treatment plants.

Corrosion of wastewater conveyance and treatment systems induced by the presence of hydrogen sulfide can cause rapid and extensive damage to concrete and metal sewer handling infrastructure used in the transport and treatment of wastewater causing premature failures. Some of these failures are catastrophic such as street collapses and sewer blockages, etc. Hydrogen sulfide induced corrosion generally requires costly premature replacement and/or rehabilitation of pipes, manholes, lift stations, and pump stations.

- Warren Environmental Epoxy attained the highest test scores as rated by the Redner and CIGMAT testing results.

- Spectrashield and Spraywall test results indicate adhesion anomalies. Low adhesion values increase the risk of microbial colonization at the coating /concrete interface, potentially creating a corrosive environment increasing the probabilities of corrosion attack resulting in cement paste loss, reinforcing steel corrosion and structural damage.

The results of chemical resistance of the materials indicate that all materials passed the respective tests.

Conclusions

The research clearly confirms the importance of practical application, moisture tolerance, adhesion, chemical resistance and hydrostatic pressure performance for the rehabilitation of manholes and other structures exposed to corrosive environments and hydrostatic pressure. Of the products tested. Warren Environmental Epoxy testing results confirms the ability of the coating system being able to perform under wet conditions.

The tests indicate that even with a high cement paste loss, and profile exceeding 25 mm (1 in.) in the unprotected concrete tanks as depicted in the Redner report, the Warren Environmental Epoxy test yielded superior test scores than all other systems included in this report. The Spraywall final test comments indicate variable bond, shallow pinholes, but no acid penetration, and all Specialty Concrete Liners failed.

The research also indicates that according to CIGMAT testing, Warren Environmental Epoxy S-301 outperforms Spectrashield in adhesion performance in accordance with ASTM-D4541-85

Warranty of the products:

- Warren Environmental Epoxy: 100% materials and labor bonded warranty for 5 years of initial completion of work on a structure; when the materials are applied by a Warren Environmental Epoxy approved applicator. The damage will be repaired to restore the lining at no cost to the Owner within 60 days after written notification of the failure. Failure does not include damage resulting from mechanical, chemical abuse nor act of God. Mechanical or chemical abuse means exposing the lined surfaces of the structure to any mechanical force or chemical substance not customarily present or used in connection with structures of the type involved. There are no warranties express or implied other than those specifically stated in this section. Any liability for consequential and incidental damages is expressly disclaimed. Liability is limited to and shall not exceed the purchase price paid.

- SprayWall Warranty and Disclaimer. As best determined, the technical data represented for all Sprayroq products is deemed to be accurate. All products are to be applied by trained and approved Sprayroq Certified Partners only and in strict accordance with the directions for usage and installation of the Sprayroq product.
  Sprayroq guarantees the products to conform to the quality assurance procedures established by Sprayroq and its resin blending partners. We assume no responsibility for coverage, performance or injuries resulting from the use of our products.

  Liability, if any, is limited to the replacement of the product for a period of one year from the date of application only. Sprayroq is not responsible for any treble expenses, liquidated damages or related labor expenses stemming from the use of this product. No other warranty is made by Sprayroq, expressed or implied, statutory or by operation of the law, including merchantability and fitness for a particular purpose.

- CCI Spectrum, Inc. (manufacturer) and Applicator warrant the SPECTRASHIELD manhole liner against failure for a period of 10 years. Failure will be deemed to have occurred if the protective lining fails to (a) prevent the internal deterioration or corrosion of the structure (b) protect the substrate and environment from contamination by effluent. If any such failure occurs within 10 years of initial completion of work on a structure, the damage will be repaired to restore the lining at no cost to the Owner within 60 days after written notification of the failure. Failure does not include damage resulting from mechanical, chemical abuse or act of God. Mechanical or chemical abuse means exposing the lined surfaces of the structure to any mechanical force or chemical substance not customarily present or used in connection with structures of the type involved. There are no warranties expressed nor implied other than those specifically stated in this section 1.03. Any liability for consequential and incidental damages is expressly disclaimed. Liability is limited to and shall not exceed the purchase price paid.

Recommendations

Based on the performance results simulating actual application conditions, the three choices identified in the order of performance are recommended:

- First Choice: Warren Environmental Epoxy

The Warren Environmental Epoxy is considered the first choice due to ease of application, moisture tolerance properties enabling to line the entire manhole invert, sealing the upstream and downstream manhole/pipe interface, excellent adhesion to wet concrete, good chemical resistance, infiltration mitigation properties and 5 years 100% bonded warranty.

- Second Choice: SprayWall System

The Spraywall System is considered the second choice because it’s limitations of application to wet concrete hindering adhesion performance, and warranty only covering only the replacement of the product for a period of three years.

- Third Choice: Spectrashield System

The Spectrashield System is considered the third choice due to low adhesion test results. The application specification reviewed do not including invert lining, hence not sealing the invert and upstream and downstream manhole/pipe interface. Not sealing the entire invert and manhole pipe interface can allow infiltration; additionally, it provides an edge where wastewater could migrate between the liner and the substrate potentially creating a corrosive environment. Low adhesion values could allow infiltration between the manhole structure and the coating thus creating an environment where bacteria could colonize increasing the risk of microbial induced corrosion. Finally, detection of damage to the host structure resultant from the potential corrosion risk can be difficult to detect because of the multi-layer system design.

The performance of any material will vary widely for a many of reasons. The recommendations below will determine the quality of the work and the longevity of the coating system installed.

A properly written and administered contract inclusive of quality management system (QMS) requirements and suitable specifications with controls and oversight mechanisms are equally important to the proper selection of a protective coating and/or lining system. Qualified auditing oversight to confirm procedural conformity by a third party NACE Certified Coatings Inspector, knowledgeable in the area of wastewater infrastructure coating and lining system applications, would assure contractual compliance during the construction phase. Qualified NACE auditing oversight (QA) has proven to be an effective approach to assure contractual and procedural conformity

It is a well documented fact that properly written and administered contracts can minimize the owners' risk and inspection requirements by placing quality control responsibility where it belongs, on the contractor.

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