THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency **NSF International**

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**Infrastructure Rehabilitation Technologies**	
APPLICATION:	**Coatings for Wastewater Collection Systems**	
TECHNOLOGY NAME:	**Protective Liner Systems Epoxy Mastic PLS-614 (PLS-614)**	
TEST LOCATION:	**University of Houston, CIGMAT**	
COMPANY:	**Protective Liner Systems, Inc.**	
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EPA created the ETV program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The program's goal is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF), in cooperation with the U.S. Environmental Protection Agency (EPA), operates the Water Quality Protection Center (WQPC), one of six centers under the Environmental Technology Verification (ETV) Program. The WQPC recently evaluated the performance of the Protective Liner Systems PLS-614 epoxy mastic, marketed by Protective Liner Systems, Inc. The PLS-614 coating was tested at the University of Houston's Center for Innovative Grouting Materials and Technology (CIGMAT).

TECHNOLOGY DESCRIPTION

The following description of the Protective Liner Systems coating material (PLS-614) was provided by the vendor and does not represent verified information.

Protective Liner Systems' PLS-614 is a 100% solids epoxy coating used for structural concrete protection, rehabilitation and repair, and is designed to be applied by trowel or spray. The PLS-614 system is formulated to provide a monolithic structural coating or patch for rehabilitation of concrete structures and protection against wear, corrosion, infiltration and exfiltration.

VERIFICATION TESTING DESCRIPTION - METHODS AND PROCEDURES

The objective of this testing was to evaluate PLS-614 used in wastewater collection systems to control the deterioration of concrete and clay infrastructure materials. Specific testing objectives were (1) to evaluate the acid resistance of PLS-614 coated concrete specimens and clay bricks, both with and without holidays (small holes intentionally drilled through the coating and into the specimens to evaluate chemical resistance), and (2) determine the bonding strength of PLS-614 to concrete and clay bricks.

Verification testing was conducted using relevant American Society for Testing and Materials (ASTM)[(1)] and CIGMAT[(2)] standards, as described below. Product characterization tests were conducted on the coating material and the uncoated concrete and clay specimens to assure uniformity prior to their use in the acid resistance and bonding strength tests. Protective Liner Systems' representatives were responsible for coating the concrete and clay specimens, under the guidance of CIGMAT staff members. The coated specimens were evaluated over the course of six months.

PERFORMANCE VERIFICATION

(a) Holiday Test - Chemical Resistance

PLS-614 coated concrete cylinders and clay bricks were tested with and without holidays (small holes intentionally drilled through the coating) in deionized (DI) water and a 1% sulfuric acid solution (pH=1). A total of 20 coated concrete specimens and 20 coated clay brick specimens were exposed. Specimens were cured for two weeks prior to creation of 0.12 in. and 0.50 in. holidays. The 0.12 in. holidays were exposed to both DI water and acid solution, while the 0.50 in. holidays were exposed only to the acid solution. Observation of the specimens at 30 and 180 days was made for changes in appearance such as blistering or cracks in the coating around the holiday or color changes in the coating. Control tests were also performed using specimens with no holidays. A summary of the chemical exposure observations is presented in Table 1.

Table 1. Summary of Chemical Exposure Observations

Specimen Material (Coating Condition)	DI Water (days)				1% H_2SO_4 Solution (days)				Comments
	Without Holidays		With Holidays		Without Holidays		With Holidays		
	30	180	30	180	30	180	30	180	
Concrete – Dry	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Color change in coating submerged in acid solution.
Concrete – Wet	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Color change in coating submerged in acid solution.
Clay Brick – Dry	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Color change in coating submerged in acid solution.
Clay Brick – Wet	N (2)	N (2)	N (2)	N (2)	N (2)	N (2)	N (4)	N (4)	Color change in coating submerged in acid solution.

N = No blister or crack; (n) = Number of specimens.

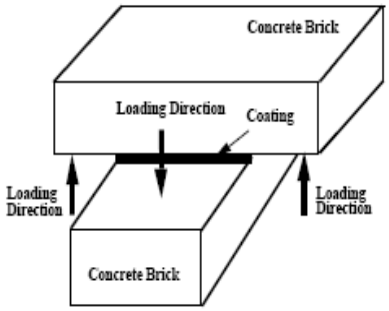
A specimen made only of PLS-614 was submerged in water for 10 days, showing no weight change over the period. Over an exposure time of 180 days, coated concrete specimens with no holidays showed less than 0.7% gain in DI water and acid exposures, as did clay brick specimens exposed to DI water. Coated clay brick exposed to acid showed a 2-7% weight gain. With holidays, coated concrete specimens showed up to 1.2% weight change, while coated clay brick specimens showed 5-7% gains. Changes in the diameters/dimensions of the specimens at the holiday levels were negligible after 180 days of exposure.

(b) Bonding Strength Tests (Sandwich Method and Pull-Off Method)

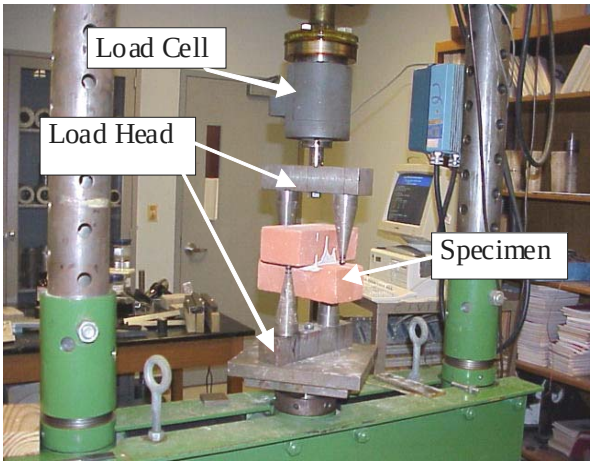
Bonding strength tests were performed to determine the bonding strength between the PLS-614 coating and concrete/clay brick specimens over a period of six months. Eight sandwich (4 dry-condition, 4 wet-condition) and sixteen pull-off (8 dry-condition, 8 wet-condition) tests were performed on both coated concrete samples and coated clay bricks.

Sandwich Test Method (CIGMAT CT 3)

CIGMAT CT 3, a modification of ASTM C321-94, was used for the testing. PLS-614 was applied to form a sandwich between a like pair of rectangular specimens (Figure 1 (a)), both concrete brick and clay brick, and then tested for bonding strength and failure type following a curing period. The bonding strength of the coating was determined using a load frame (Figure 1 (b)) to determine the failure load and bonding strength (the failure load divided by the bonded area). The sandwich bonding tests were completed at 30, 90 and 180 days after application of the PLS-614.



(a) Test specimen configuration



(b) Load frame test setup

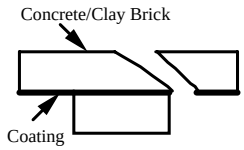
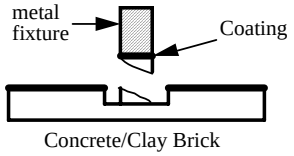
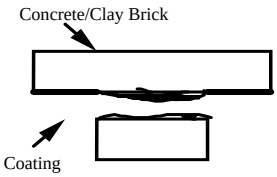
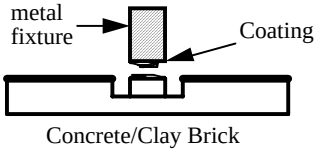
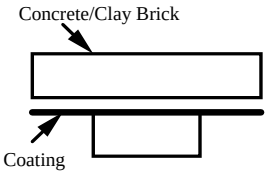
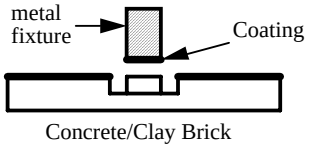
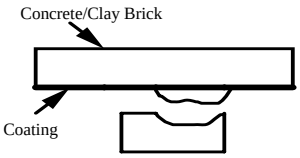
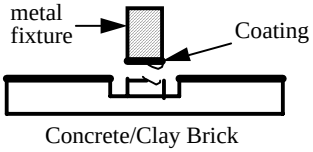
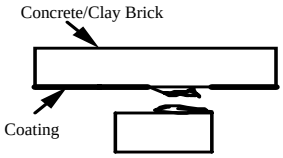
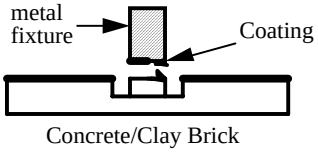
Figure 1. Bonding test arrangement for sandwich test.

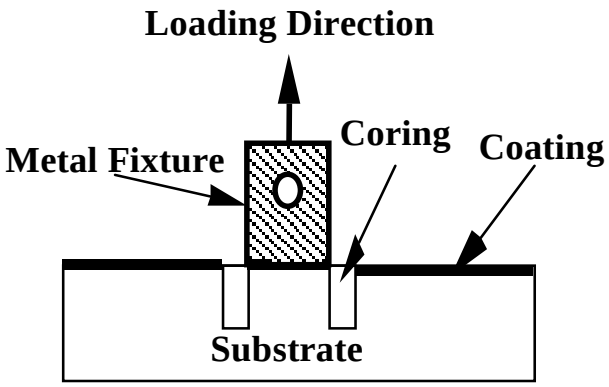
Dry-coated specimens were dried at room conditions for at least seven days before they were coated, while wet-coated specimens were immersed in water for at least seven days before the specimens were coated. Bonded specimens were cured under water up to the point of testing. The type of failure was also characterized during the load testing, as described in Table 2.

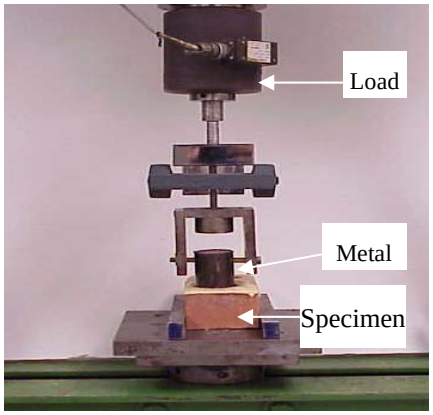
Pull-Off Method (CIGMAT CT 2)

Per CIGMAT CT 2, a 2-in. diameter circle was cut into coated concrete prisms and clay bricks to a predetermined depth to isolate the coating, and a metal fixture was glued to the isolated coating section using a rapid setting epoxy. Testing was completed on a load frame with the arrangements shown in Figure 2, with observation of the type of failure, as indicated in Table 2. The specimens were prepared in the same manner as for the sandwich test. The specimens were stored under water in plastic containers and the coatings were cored 24 hrs prior to the testing. The bonding tests were completed at 21, 60 and 180 days after application of the PLS-614. Results of the bonding tests are included in Table 3.

Table 2. Failure Types in Sandwich and Pull-Off Tests

Failure Type	Description	Sandwich Test	Pull-off Test
Type-1	Substrate Failure		
Type-2	Coating Failure		
Type-3	Bonding Failure		
Type-4	Bonding and Substrate Failure		
Type-5	Bonding and Coating Failure		





(a) Specimen preparation **(b) Load frame arrangement**

Figure 2. Pull-off test method load frame arrangement.

Table 3. Summary of Test Results for Bonding Strength Tests (12 Specimens for Each Condition)

Substrate – Application Condition	Test [1]	Failure Type [2] – Number of Failures					Failure Strength (psi)	
		1	2	3	4	5	Range	Average
Concrete – Dry	Sandwich	4					232 – 293	269
	Pull-off	1			7		107 – 304	205
Concrete – Wet	Sandwich	3			1		257 – 321	287
	Pull-off	5			3		190 – 350	234
Clay Brick – Dry	Sandwich	4					314 – 350	335
	Pull-off	3			5		187 – 321	253
Clay Brick – Wet	Sandwich	4					338 – 384	366
	Pull-off	3			5		181 – 374	264

[1] Sandwich test (CIGMAT CT-2/Modified ASTM D 4541-85) or Pull-off test (CIGMAT CT-3/ASTM C 321-94).
[2] See Table 2.

(c) Summary of Verification Results

The performance of the Protective Liner System, Inc. PLS-614 epoxy mastic for use in wastewater collection systems was evaluated for chemical resistance and the bond of the coating with both wet and dry substrate materials, made up of concrete and clay brick. The type of bonding test, whether sandwich test or pull-off test, impacted the mode of failure and bonding strength for both substrate materials. The testing indicated:

General Observations

- Samples of the coating material alone showed no weight gain when exposed to water over a 10-day period.
- None of the coated concrete or clay brick specimens, with or without holidays, showed any indication of blisters or cracking during the six-month holiday-chemical resistance tests.
- There were no observed changes in the dimensions of the coated concrete or clay brick specimens at the holiday levels for either DI or acid exposures.
- All 48 of the bonding tests resulted in substrate and substrate/bonding failures, with 27 substrate failures (Type-1) and 21 bonding/substrate failures (Type-4).

Concrete Substrate

- Weight gain was < 0.60% for any of the coated concrete specimens without holidays.
- Weight gain was < 1.5% for any of the coated specimens with holidays for both water and acid exposures.
- Dry-coated concrete failures were mostly (7 of 12) bonding and concrete substrate (Type -4) failures, with the remainder being concrete substrate (Type-1) failures.
- Average tensile bonding strength for dry-coated concrete specimens was 226 psi, with individual specimens ranging from 107 to 304 psi.
- Wet-coated concrete failures were mostly (8 of 12) concrete substrate (Type-1) failures, with the remainder being bonding and concrete substrate (Type-4) failures.
- Average tensile bonding strength for wet-coated concrete specimens was 252 psi, with individual specimens ranging from 190 to 350 psi.

Clay Brick Substrate

- Without holidays, weight gain was < 0.45% for water exposed coated clay brick specimens; weight gain for acid exposed coated clay brick specimens was about 2-7%.
- With holidays, weight gains were > 5% for water exposed specimens and generally > 6% for acid exposed specimens; the holiday size did not make a significant difference in weight gain.
- Dry-coated clay brick failures were mostly (7 of 12) clay brick substrate (Type -1) failures, with the remaining five being bonding and clay brick substrate (Type-4) failures.
- Average tensile bonding strength for dry-coated clay brick specimens was 280 psi, with individual specimens ranging from 187 to 350 psi.
- Wet-coated clay brick failures were predominantly (7 of 12) clay brick substrate (Type-1) failures, with the remaining five being bonding and clay brick substrate (Type-4) failures.
- Average tensile bonding strength with-wet coated clay brick was 286 psi, with individual specimens ranging from 181 to 384 psi.

Quality Assurance/Quality Control

NSF completed a technical systems audit prior to the start of testing to ensure that CIGMAT was equipped to comply with the test plan. NSF also completed a data quality audit of at least 10% of the test data to ensure that the reported data represented the data generated during testing.

Original signed by Sally Gutierrez	*October 6, 2010*	*Original signed by Robert Ferguson*	*November 2, 2010*
Sally Gutierrez	Date	Robert Ferguson	Date
Director		Vice President	
National Risk Management Research Laboratory		Water Systems	
Office of Research and Development		NSF International	
United States Environmental Protection Agency			

Availability of Supporting Documents

Referenced Documents:

1) Annual Book of ASTM Standards (1995), Vol. 06.01, Paints-Tests for Formulated Products and Applied Coatings, ASTM, Philadelphia, PA.
2) CIGMAT Laboratory Methods for Evaluating Coating Materials, available from the University of Houston, Center for Innovative Grouting Materials and Technology, Houston, TX.

Copies of the *Test Plan for Verification of Protective Liner Systems PLS-614 Coating for Wastewater Collection Systems* (March 2009), the verification statement, and the verification report (NSF Report Number 10/34/WQPC-SWP) are available from:

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