Testing Warren Environmental, Inc. Product for Use in Coating Wastewater Concrete and Clay Brick Facilities in the CIGMAT Laboratory

Coating Material

S - 301 (Dry and Wet)

ABBREVIATED TEST RESULTS

FINAL REPORT

by

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Evaluating Warren Environmental, Inc. Product

S - 301 (Dry and Wet Coating)

1. ABSTRACT

Microbially induced corrosion in sewer facilities requires rapid in situ rehabilitation of the cement concrete/clay brick elements. Coating wastewater facilities is one method currently being adopted, but there is no systematic method for evaluating the performance of these coating materials under wet and dry conditions. The aim of this study was to evaluate Warren Environmental, Inc. coating material with a combination of full scale and laboratory tests for applications in rehabilitation and new construction.

Full scale pressure chambers (hydrostatic tests) were designed and built to evaluate the application and performance of the coating materials on concrete substrate under a hydrostatic pressure of over 10 m (32 ft.) of water simulating the ground water conditions. Coated concrete and clay bricks with holidays (pinholes) were used to study the chemical resistance under acidic environment (modified ASTM G20-88). To quantify bonding strength between the coatings and substrates two ASTM standard testing methods were used (modified ASTM D 4541-85 and ASTM C321-94). Results based on the full scale test (seven months) and laboratory tests (six months) of S-301 coating are discussed in this report.

2. INTRODUCTION

Concrete is the most widely used construction material in large wastewater treatment plants. It is commonly used for below grade wet wells or holding tanks; manholes; sewer pipelines and open top channels. Manholes made of clay bricks are also very common. Many municipalities are discovering that particular concrete structures and brick manholes in the wastewater collection and treatment facilities are subjected to corrosive environments and are degrading rapidly. There are several methods in practice to control the degradation of wastewater facilities [Kienow et al., 1993]. The primary goal of rehabilitating these facilities is to return the structure to its original working conditions by in situ methods. Addition of base materials at regular intervals has turned out to be relatively expensive especially when there is regular sewer flooding as the case of sewer facilities in the City of Houston, Houston, Texas. Cleaning the pipes regularly by increasing the velocities of flow has not proved to be effective. Coating is one method currently being adopted but the effectiveness of this method for rehabilitating lift stations and sewer treatment facilities is still in question.

Sewer facilities are wet and experience hydrostatic pressure under normal service conditions. Application of coating materials to such surfaces is considered a challenge and must be evaluated. Bonding between the concrete/clay brick surface and the coating material is another important factor that must be evaluated to determine the performance of the coating. Chemical resistance of coatings to the above mentioned corrosive environment is also very important.

To select the coating systems to solve the concrete corrosion problems, their performance and installation must be well understood. Restoring concrete with coatings requires considering concrete surface conditions (strength and moisture content) and the porosity of the concrete. The minimum recommended surface strength of concrete for using coatings is in the range of 1.4 to 1.75 MPa (200-300 psi) [Soebbing et al. 1996]. A sufficient quantity of water at the concrete surface can react with the coating material and affect the setting and the adhesion of the coating systems. The surface moisture will depend on the porosity of the concrete and hydrostatic pressure due to the water table. Coatings can debond and blister if the hydrostatic pressure exceeds the tensile adhesion of the coating material. Concrete deterioration can range from slight etching or partial loss of surface cement binder to complete loss of cement binder. Complete binder loss yields exposed coarse aggregates and reinforcing steel which will further accelerate corrosion and cracking and spalling of the concrete. For satisfactory performance, the coating needs to be holiday-free. Many early installations did not ensure holiday- free coating which resulted in premature failure of the coatings.

Coatings can stay in contact with the concrete and protect it from physical/chemical/biological degradation. Durability of a coating material for concrete/clay brick structures is as important as its ability to perform in intended applications. Durability is concerned with life expectancy or endurance characteristics of the coating material. A durable coating is one which will withstand, to a satisfactory degree, the effect of service conditions to which it will be subjected. There is only limited information in the literature on the performance of coatings in concrete pipes and the results are not conclusive on the durability of coating materials. Several coating materials were studied by the Los Angeles County and the results show that only a low percentage of coatings performed well under their testing conditions [Redner et al., 1992 and 1994]. Hence, it is important to identify good coating materials for application in the Houston area for protecting the structures in the wastewater treatment and collection facilities.

Since several factors in the field can affect the performance of coating, it is important to identify the important factors through controlled experiments where important variables are studied one at a time. In this study, a comprehensive testing program was developed for evaluating Coating S-301 (dry and wet) coating materials for concrete/clay brick rehabilitation.

3. OBJECTIVES

The objective of this study was to evaluate Coating S-301 (dry and wet) for use in sewer rehabilitation projects. Specific objectives are as follows: (a) to evaluate the application and performance of coatings on a concrete surface 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.

4. MATERIALS AND TESTING PROGRAM

4. 1. *Materials*

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°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.

4. 2. *Testing Program*

(i) 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.

(a) 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 (Fig. 1) [Vipulanandan et al., 1996]. 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.).

Wet test: **(S-301 coating)** The 900 mm (36-inch) concrete pipe was installed in the test chamber and pressurized at 105 kPa (15 psi) for at least four weeks before applying the coating.

(b) Measurements

Visual Inspection: The coated surfaces were visually inspected regularly and information on blistering, spalling, discoloring and cracking were noted and photographed. ASTM D 714-87 was used to characterize the blister size and frequency and will be 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.

Application

S-301 coating was applied successfully under hydrostatic test conditions. Coating was applied with ease. Coating was inspected during and immediately after application. No immediate defects (blistering, cracking, discoloration, spalling, sticking to the finger after 48 hours of application, scratch-off) were observed on the coated surfaces. Wet coating was applied after acid etching and water jetting the concrete surface at the University of Houston testing site (June 14, 1996).

Rating:

(i) Wet coating (S-301) passed* the application test. Coverage** of the concrete surface was good. Overall finish*** was good.

*Passing means (1) no blistering, (2) no cracking, (3) no discoloration, (4) no spalling, (5) not stick to the finger after 48 hours of application and (6) cannot scratch-off.

** Coverage rating was selected from good, satisfactory or bad. Good rating means no visible spot of concrete surface; Satisfactory rating means a few small spots of visible concrete surface; Bad rating means several spots of visible concrete surface.

***Overall finish rating was selected from good, satisfactory or bad based on the quality of the application job.

Performance

The coating was tested under a hydrostatic pressure of 105 kPa (15 psi) over a period of eight months. For inspection purposes each eight feet length of 900 mm (36 in.) pipe was divided into 12 (4 X3) sections of approximate area of 900 sq.in (6.3 sq.ft) each. The coating was inspected on a regular basis to identify any visible defects and mapped on 4 X 3 format as shown in Table B1. Table B1 summaries the performance of S-301 (wet) in each section of the pipe with photographs in Fig. B1. Each section was evaluated for (i) overall condition (ii) surface texture (iii) blistering (iv) cracking and (v) change in color and. In all of these categories the coating performed well. The performance of S-301 (wet) is summarized in Tables B2 with photographs in Fig. B2.

Overall Rating:

(i) Wet coating (S-301) passed the performance test in all categories ((i) through (v))

S-301(Wet Coating)

Concrete

ASTM D 4541-85: A total of 4 tests were performed. Both Type 1 and Type 4 failures were observed in the tests. The average bonding strength from the tests was 219 psi (1.5 MPa) (Table D2). Four in-situ bonding tests were performed. Type 1, 2 and 4 failure types were observed. The average bonding strength was 434 psi. The bonding strength of the coating with wet concrete in the in-situ tests was very good.

ASTM C 321-94: A total of 2 tests were performed. All failures were Type 1. Average bonding strength from laboratory tests was greater than 289 psi (2.0 MPa) (Table D6).

Summary: Both Type 1 and Type 4 failures were observed in ASTM D 4541 and ASTM C 321 tests. The average bonding strength from ASTM D 4541 and ASTM C 321 test were 219 psi(1.5 MPa) and 289 psi (2.0 MPa) respectively. The average bonding strength in the in-situ tests was 434 psi. Good bonding strength with wet concrete.

Clay Brick

ASTM D 4541-85: A total of 4 tests were performed. 1 of them was rejected due to low clay brick strength. All failures from this test were Type 1. Average bonding strength was 241 psi (1.7 MPa) (Table D4)

ASTM C 321-94: A total of 2 tests were performed. All failures were Type 1. Average bonding strength from laboratory tests was greater than 187 psi (1.3 MPa) (Table D8).

Summary: All failures from ASTM C321 test were Type 1. The average bonding strength from ASTM D 4541 was 241 psi(1.7 MPa) and form ASTM C 321 test was 187 psi (1.3 MPa) . Good bonding strength with wet clay brick.

6. CONCLUSIONS

A combination of full-scale and laboratory tests were used to evaluate the performance of S-301 (dry and wet) for coating concrete and clay bricks. Based on the test results following observations are advanced.

(1) S-301 (wet) passed the application (eight evaluation categories) and the performance (five evaluation categories) in the hydrostatic test.

(2) All (100%) the dry coated concrete and 94% wet coated concrete passed the holiday-chemical resistance tests after six months. Pinholes were found on S-301 coated concrete specimens in the chemical resistant test.

(3) All the S-301 coated clay bricks (dry and wet) with and without holidays passed the chemical resistant test after six months (100% passed).

(4) S-301 (dry and wet) had good bonding strength with concrete and clay brick

7. REFERENCES

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Table C3. Holiday Test Results for S-301 Coated Concrete (Dry) after Six (6) Months of Immersion (Modified ASTM G20-88)

Concrete	Holiday	Medium and Rating (No. of Specimens)			Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4	30% H_2SO_4		
Dry	No Holiday	P(1) P(1)*	P(1) P(1)*	P(1) P(1)*	6 (100/0/0)	Pass
	1/8 inch	P(1)	P(1)	P(1)	3 (100/0/0)	Pass
	1/4 inch	P(1)	P(2)	P(2)	5 (100/0/0)	Pass
	1/2 inch	---	P(1)	P(1)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	6 (100/0/0)	16 (100/0/0)	Total of 16 specimens tested
Remarks	After six months of immersion	Pass	Pass	Pass		All pass(100%)

P=Pass; B=Blister; F=Failure; PB=Pass with Blister
*Specimens developed pinholes on the coating surface.

Table C4. Holiday Test Results for S-301 Coated Concrete (Wet) after Six (6) Months of Immersion (Modified ASTM G20-88)

Concrete	Holiday	Medium and Rating (No. of Specimens)			Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4	30% H_2SO_4		
Wet	No Holiday	P(2)*	P(2)*	P(1) P(1)*	6 (100/0/0)	Pass
	1/8 inch	P(1)	P(1)	P(1)	3 (100/0/0)	Pass
	1/4 inch	P(1)	P(2)	P(1) P(1)*	5 (100/0/0)	Pass
	1/2 inch	---	P(1)	F(1)	2 (50/50/0)	One specimen failed
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	6 (83/0/17)	16 (94/0/6)	Total of 16 specimens tested
Remarks	After six months of immersion	Pass	Pass	One specimen failed		94% of the specimens passed the test.

P=Pass; B=Blister; F=Failure; PB= Pass with Blister.
*Specimens developed pinholes on the coating surface.

Table C7. Holiday Test Results for S-301 Coated Clay Brick (Dry) after Six (6) Months of Immersion (Modified ASTM G20-88)

Concrete	Holiday	Medium and Rating (No. of Specimens)			Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4	30% H_2SO_4		
Dry	No Holiday	P(2)	P(1) P(1)*	P(2)	6 (100/0/0)	Pass
	1/8 inch	P(1)	P(1)	P(1)	3 (100/0/0)	Pass
	1/4 inch	P(1)	P(2)	P(2)	5 (100/0/0)	Pass
	1/2 inch	---	P(1)	P(1)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	6 (100/0/0)	16 (100/0/0)	Total of 16 specimens tested
Remarks	After one (1) month of immersion	Pass	Pass	Pass		All pass(100%) But some of the specimens have natural pinholes

P=Pass; B=Blister; F=Failure; PB=Pass with Blister .
*Specimens developed pinholes on the coating surface.

Table C8. Holiday Test Results for S-301 Coated Clay Brick (Wet) after Six (6) Months of Immersion (Modified ASTM G20-88)

Concrete	Holiday	Medium and Rating (No. of Specimens)			Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4	30% H_2SO_4		
Wet	No Holiday	P(2)*	P(2)	P(2)	6 (100/0/0)	Pass
	1/8 inch	P(1)	P(1)	P(1)	3 (100/0/0)	Pass
	1/4 inch	P(1)	P(2)	P(2)	5 (100/0/0)	Pass
	1/2 inch	---	P(1)	P(1)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	6 (100/0/0)	16 (100/0/0)	Total of 16 specimens tested
Remarks	After one (1) month of immersion	Pass	Pass	Pass		All pass(100%) But some of the specimens have natural pinholes

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.
*Specimens developed pinholes on the coating surface.

Table D3. Bonding Strength of S-301with Dry Clay brick (ASTM D4541-85)

Clay brick	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Dry	31	X					220
	31	#					156#
	286	#					156#
	286	X					241
Total No. (% Failure)		2 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 successful tests, Total of 4 tests.
Remarks	Up to nine (9) months	Good bonding	None	None	None	None	100% Type 1 failure. Average bonding strength was 231 psi (1.6 MPa).

Type 1 = Concrete failure; Type 2 = Coating failure; Type 3 = Bonding failure;
Type 4 = Combined concrete and bonding failure;
Type 5 = Combined coating and bonding failure;
Rejected tests due to low concrete strength

Table D4. Bonding Strength of S-301with Wet Clay Brick (ASTM D4541-85)

Clay brick	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Wet	31	X					192
	31	X					343
	286	X					189
	286	#					151#
Total No. (% Failure)		3 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	Total of 4 specimens tested
Remarks	Up to nine (9) months	Good bonding	None	None	None	None	100% Type 1 failure. Average bonding strength is 241 psi(1.7 MPa)

Type 1 = Concrete failure; Type 2 = Coating failure; Type 3 = Bonding failure;
Type 4 = Combined concrete and bonding failure;
Type 5 = Combined coating and bonding failure;
Rejected tests due to low concrete strength

Table D5. Bonding Strength of S-301with Dry Concrete (ASTM C321-94)

Concrete	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Dry	24	X					321
	283	X					322
Total No. (% Failure)		2 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	Total of 2 specimens tested
Remarks	More than nine (9) months	Good bonding strength	None	None	None	None	100% Type 1 failure. Good bonding strength. Average bonding strength is 322 psi(12.3 MPa).

Type 1 = Concrete failure; Type 2 = Coating failure; Type 3 = Bonding failure;
Type 4 = Combined concrete and bonding failure;
Type 5 = Combined coating and bonding failure;

Table D 6. Bonding Strength of S-301with Wet Concrete (ASTM C321-94)

Concrete	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Wet	24	X					287
	283	X					291
Total No. (% Failure)		2 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	Total of 2 specimens tested
Remarks	More than nine (9) months	Good bonding strength	None	None	None	None	100% Type 1 failure. Good bond ing strength. Average bonding strength is greater than 289 psi (2.0 MPa).

Type 1 = Concrete failure; Type 2 = Coating failure; Type 3 = Bonding failure;
Type 4 = Combined concrete and bonding failure;
Type 5 = Combined coating and bonding failure;