Testing Epoxytec Product for Coating Wastewater Concrete and Clay Brick Facilities in the CIGMAT Laboratory

Coating Material

Uroflex (Dry and Wet Conditions)

FINAL REPORT

by

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Evaluating a Epoxytec Product:

Uroflex (Dry and Wet Conditions)

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 Epoxytec coating material (Epoxytec Uroflex) with a series of laboratory tests for applications in rehabilitation and new construction.

Coated concrete and clay bricks with holidays (pinholes) were used to study the chemical resistance under acidic environment CIGMAT CT-1 (modified ASTM G 20-88). During this test, specimens were inspected visually and weight changes in the coated concrete (dry and wet) and clay bricks (dry and wet) specimens in D. I. water and sulfuric acid solution (pH =1) were monitored. Total of 20 coated concrete and 20 coated clay brick specimens with and without pinholes were tested. To quantify the bonding strength between the coatings and substrates (concrete and clay brick) two CIGMAT standard testing methods were used (CIGMAT CT-2 (modified ASTM D 4541-85) and CIGMAT CT-3 (modified ASTM C321-94)). Total of 48 bonding tests were performed over a study period of 6 months.

Based on the test results following could be concluded on Epoxytec Uroflex (dry and wet coating): (1) All the dry coated concrete and wet coated concrete specimens with and without holidays passed the holiday-chemical resistance tests after six months; (2) All the dry coated clay brick and wet coated clay brick specimens with and without holidays passed the holiday-chemical resistance tests after six months; (3) Uroflex coating had good bonding strength with concrete (dry and wet), and (4) Uroflex coating had good bonding strength with clay bricks (dry and wet).

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 [Vipulanandan et al. 1996, 2005]. 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 could be regular sewer flooding. Cleaning the pipes regularly by increasing the velocities of flow has not proved to be effective. Coating is one method currently being adopted for rehabilitating lift stations and sewer treatment facilities [Render 1994, Liu and Vipulanandan 1999].

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 200-300 psi (1.4 to 1.75 MPa) [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 showed 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 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 Epoxytec Uroflex (dry and wet) coating materials for concrete/clay brick rehabilitation.

3. OBJECTIVES

The objective of this study was to evaluate Epoxytec Uroflex (dry and wet) for use in sewer rehabilitation projects. Specific objectives are as follows: (a) to evaluate the acid resistance of the coated concrete and clay bricks with and without holidays; and (b) 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*

Uroflex: Based on the manufacturer's data sheet, it is a two coat system ((three coats when wet –used Epoxytec B2 primer (Appendix D)) with 100% solid urethane modified epoxy. The coating was applied after cleaning with wire brush. The coating was red in color and a pure coating sample is shown in Fig. 1.

4. 2. *Testing Program*

The coating was applied to the wet and dry concrete / clay brick. Application temperature was 65^{o}F. Primer was used before coating the specimens. Dry coating condition simulates the new concrete surface while the wet condition simulated the rehabilitation condition.

Figure 1. Sample of Uroflex coating

(a) Holiday Test - Chemical Resistance CIGMAT CT-1 (Modified ASTM G 20-88)

In order to study the chemical resistance ASTM G 20-88 test was modified to use with concrete and clay brick materials (CIGMAT CT-1). 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 94 mm (3.75″) X 69 mm (2.75″) X 200 mm (8″) for this test. Dry and wet specimens were coated on all sides and tested. For the test two radial holes were drilled into the specimen approximately 15 mm (3/5″) deep as shown in Fig.2.

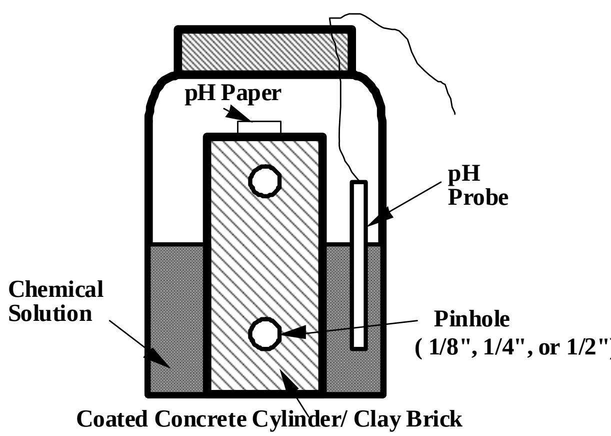
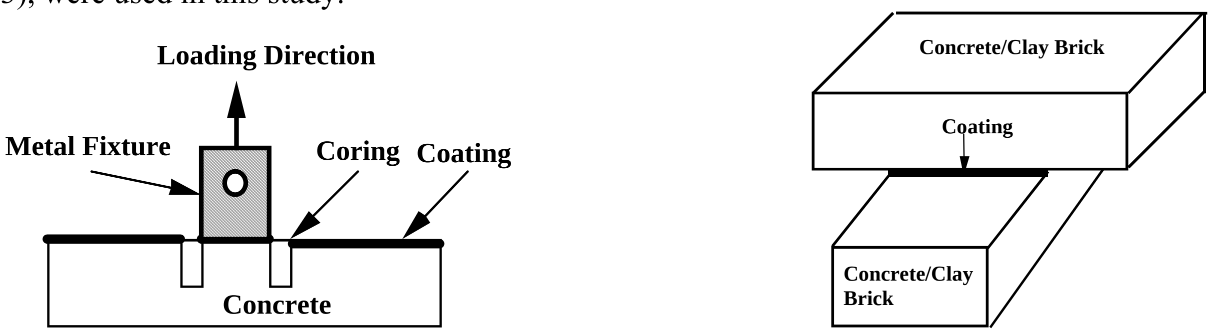


Figure 2 Chemical immersion tests

In this test, the changes in the weight were measured and appearances of specimens were visually inspected at regular intervals. The two test reagents selected for this study are (1) deionized (DI) water (pH = 5 to 6) and Sulfuric acid solution (pH = 1) were selected for testing the coated materials. Control tests were performed with no holidays. Total of 40 specimens were tested with the coating material.

(b) ***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 six months. Two modified ASTM standards, ASTM D 4541 (CIGMAT CT 2) and ASTM C 321 (CIGMAT CT 3), were used in this study.



(a) Modified ASTM D 4541 test specimen (b) ASTM C 321 test specimen

Figure 3. Configurations of modified (a) ASTM D 4541 and (b) ASTM C 321 tests

CIGMAT CT-2 Test (modified ASTM D 4541-85):

Modified ASTM D 4541 test setup is shown in Fig. 3(a). This test evaluated the pull-off strength of coating films to concrete substrate. The ASTM D 4541 test method was used to determine the bonding strength of Epoxytec Uroflex to concrete/clay substrate. Prism concrete specimens were coated in the same manner as the specimens for the immersion test. Bonding strength was determined at the beginning and end of the immersion test.

In this test, a 51 mm (2″) diameter circular area was selected for testing (Fig. 3 (a)). Coated concrete was cored using a diamond core drill to isolate the coating. A metal fixture was then glued to the isolated coating section using a rapid setting epoxy. Total of 24 tests were performed during the period covered in this report.

Test specimens were fixed to the test machine as shown in Fig. 4. A constant rate of displacement was applied on the fixture to pull it up. The bonding strength of the coating to substrate was determined by the maximum load measured at failure. Failure types of the bonding test were also analyzed.

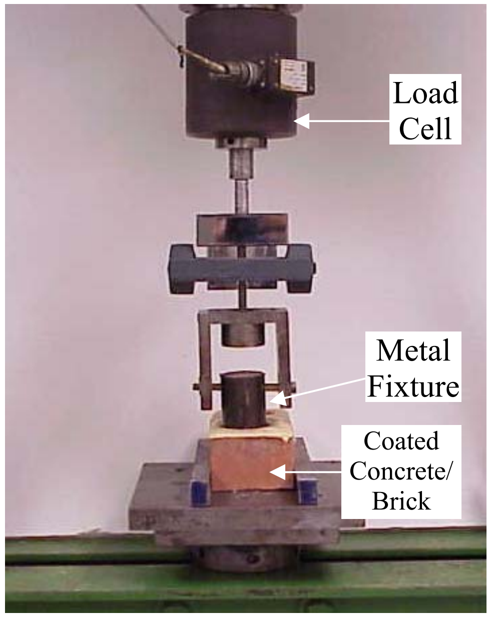


Figure 4. Modified ASTM D 4541 test setup

CIGMAT CT-3 Test (modified ASTM C 321-94):

In this test, the coating was sandwiched between a pair of rectangular concrete block or clay brick specimens (Fig. 3(b)) 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 24 tests were performed during the period of this report. Compared to modified CIGMAT CT-2 test, this is an easier test to perform since no coring or gluing of metal fixture is required. The test set-up and configuration are shown in Fig. 5.

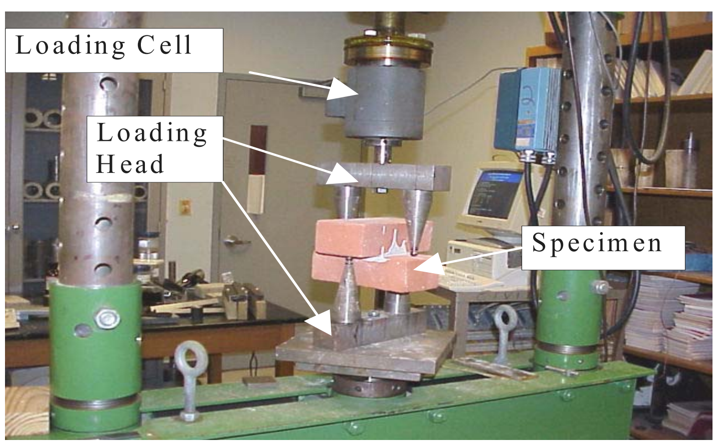


Figure 5 Bonding test setup for CIGMAT CT-3 (Modified ASTM C 321) Test

5. TEST RESULTS AND DISCUSSION

Concrete cylinders and prisms and clay bricks were first evaluated to characterize the quality and acid resistance. All the test specimens for the laboratory tests were prepared at the University of Houston Test Site over a period of three days.

5.1. Quality *Control*

In order to ensure the quality, the concrete (cylinders and blocks) and clay bricks used in this study were tested and the results are summarized in this section.

(i) *Unit Weight and Pulse Velocity*

The concrete and clay brick specimens used in this coating study characterized based on their unit weight and pulse velocity..

Concrete: The variation of pulse velocity with unit weight is shown in Fig. A1. The unit weight of concrete specimens varied between 138 pcf (21 kN/m^3) and 149 pcf (23 kN/m^3). The pulse velocity varied from 12,600 ft/sec to 16,000 ft/sec. There was no direct correlation between the pulse velocity and unit weight of concrete. The variation of pulse velocity was normally distributed (Fig. A1(b)).

Clay Brick: The variation of pulse velocity with unit weight is shown in Fig. A2. The unit weight of clay brick specimens varied between 129 pcf (20 kN/m^3) and 143 pcf (22 kN/m^3). The pulse velocity varied from 800 ft/sec to 10,500 ft/sec. There was no direct correlation between the pulse velocity and unit weight of concrete. The variation of pulse velocity was normally distributed (Fig. A2(b)).

Coating: The unit weight of coating varied from 62.6 pcf to 64.4 pcf with an average of 63.5 pcf with a coefficient of variation of 0.96%. The pulse velocity varied from 6930 ft/sec to 7285 ft/sec with an average of 7121 ft/sec with a coefficient of variation of 1.6% (Table A6).

(ii) *Chemical Resistance*

Concrete: Results are summarized in Tables A1 and A2 for concrete cylinders dry and wet respectively. Dry concrete cylinder partially submerged (50%) in water showed continuous increase in weight up to 0.4% in sixty days. The wet concrete in water showed a 0.1% increase in weight in 60 days. Weight loss and visible corrosion was observed in the dry and wet concrete specimens in the sulfuric acid solution (pH = 1)..

Clay Bricks: Results are summarized in Tables A3 and A4 for dry and wet clay brick respectively. Dry bricks in water and acids showed similar gain in weight of over 10%. No visible damage in bricks were observed. Wet bricks showed much smaller weight gain as compared to the dry bricks. Weight increase was not observed with further soaking.

Coating: Specimens immersed in water for 10 days showed no gain in weight

A. 3. *Strength*

Concrete: Compressive and flexural strength of dry and wet concrete are summarized in Table A5 in Appendix A. The minimum compressive strength of 28 days water cured concrete was 4100 psi (28 MPa) and the flexural strength was 1065 psi (7.6 MPa).

Clay Brick: Flexural strength of dry and wet clay bricks are summarized in Table A5 in Appendix A. The average flexural strength was 1136 psi and 932 psi for wet dry and wet clay bricks. The flexural strength is important for bonding test CIGMAT CT-3 (Modified ASTM C321-94).

5. 2. Coated Materials

(a) Holiday Test - Chemical Resistance

In order to evaluate the performance of Uroflex, coated concrete cylinders and clay bricks were tested with and without holidays in water and sulfuric acid solution (pH=1). Performance of Uroflex was evaluated over a period of six months from April 2009 to October 2009 in this study. Total of 20 coated concrete specimens and 20 coated clay brick specimens were tested. The results are summarized in Tables B1 through B6.

Uroflex (Dry Coating)

(i) Concrete

One month (30 days): All the specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solution (Table B.1)

Six months (180 days): All the specimens passed the test. Discoloration (DC) was observed, in the lower part of the specimens (liquid phase) and partially in the upper part of the specimens (vapor phase), immersed in sulfuric acid solution (pH=1) (Table B.3).

(ii) Clay Brick

One month (30 days): All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Six months (180 days): All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Epoxytec Uroflex (Wet Coated)

(i) Concrete

One month (30 days): All the specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solution (Table B.2)

Six months (180 days): All the specimens passed the test. Discoloration (DC) was observed, in the lower part of the specimens (liquid phase) and partially in the upper part of the specimens (vapor phase), immersed in sulfuric acid solution (pH=1) (Table B.4).

(ii) Clay Brick

One month (30 days): All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Six months (180 days): All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

(b) Bonding Strength

Bonding strengths of Epoxytech Inc. Uroflex coating on dry and wet concrete and clay brick were determined according to CIGMAT CT-2 (modified ASTM D 4541-85) and CIGMAT CT-3 (modified ASTM C 321-94) testing methods. All the coated specimens were cured under water. Both dry and wet concrete and clay brick specimens were coated to simulate the various field conditions. Performance of Epoxytec Uroflex coating was evaluated starting April, 2009 and the results are included in this report. Total of 24 bonding tests with concrete specimens and 24 with clay brick specimens have been performed. The results are summarized in Tables C2 through C9 with the type of failure.

Uroflex (Dry Coating)

(i) Concrete

CIGMAT CT-2 (modified ASTM D 4541-85): A total of 6 laboratory tests were performed. 100% Type-1(Fig. C1) failure was observed. The Average bonding strength from all the tests performed was 296 psi (2 MPa) (Table C2).

CIGMAT CT-3 (modified ASTM C 321-94): A total of 6 tests were performed. Test results are summarized in Table C6 and Figures C4, C6 and C8. All failures were Type-1. Average bonding strength from all the laboratory tests was 235 psi (1.6 MPa) (Table C6).

Summary: Type of test did not influence the mode of failure.. Type-1 failure was observed during CIGMAT CT-2 (modified ASTM D 4541) test. CIGMAT CT-3 (modified ASTM C 321-94) produced Type-1 failure. The average bonding strengths from CIGMAT CT-2 (modified ASTM D4541) tests was 296 psi (2 MPa) and from CIGMAT CT-3 (modified ASTM C 321-94) tests was 235 psi (1.6 MPa). Bonding strength with dry concrete was good.

(ii) Clay Brick

CIGMAT CT-2 (modified ASTM D 4541-85): A total of 6 tests were performed. Type-1 (68%), Type-3 (16%) and Type-5 (16%) failures were observed. The average bonding strength from all the tests was 348 psi (2.4 MPa) (Table C4).

CIGMAT CT-3 (modified ASTM C 321-94): A total of 6 tests were performed. Type 1 failure (100%) was observed in the test. Test results are summarized in Table C8 and Figures C4, C6 and C8. And the average bonding strength was 316 psi (2.1 MPa) (Table C8).

Summary: Type of test had minimal influence the dominant mode of failure (Type-1) . Type-1 (68%), Type-3 (16%) and Type-5 (16%) failures were observed during CIGMAT CT-2 (modified ASTM D 4541) test. CIGMAT CT-3 (modified ASTM C 321-94) produced 100% Type-1 failure. The average bonding strengths from ASTM D 4541 tests was 348 psi (2.4 MPa) and from ASTM C 321-94 tests was 316 psi (2.1 MPa). Bonding strength with dry clay brick was good.

Uroflex (Wet Coating)

(i) Concrete

CIGMAT CT-2 (modified ASTM D 4541-85): A total of 6 laboratory tests were performed. All the failures were Type-4 (100%). Average bonding strength from this test was 254 psi (1.7 MPa) (Table C3).

CIGMAT CT-3 (modified ASTM C 321-94): A total of 6 tests were performed. Both Type-1 (84%) and Type-4 (16%) failures were observed. Test results are summarized in Table C7 and Figures C5, C7 and C9. Average bonding strength from laboratory tests was 240 psi (1.6 MPa) (Table C7).

Summary: The average bonding strengths from CIGMAT CT-2 (modified ASTM D 4541) tests was 254 psi (1.7 MPa) and from CIGMAT CT-3 (modified ASTM C 321-94) tests was 240 psi (1.6 MPa). Based on the type of failure and the bonding strength measured, bonding strength with wet concrete was good.

(ii) Clay Brick

CIGMAT CT-2 (modified ASTM D 4541-85): A total of 6 tests were performed. All failures were Type-1 (100%). The average bonding strength was 322 psi (2.2 MPa) (Table C5).

CIGMAT CT-3 (modified ASTM C 321-94): A total of 6 tests were performed. 100% Type 1 failure was observed in the test. Test results are summarized in Table C9 and Figures C5, C7 and C9. The average bonding strength was 288 psi (2 MPa) (Table C9).

Summary: Type of test did not influence the type of failure. All failures were. Type-1. The average bonding strengths from CIGMAT CT-2 (modified ASTM D 4541) tests was 322 psi (2.2 MPa) and from CIGMAT CT-3 (modified ASTM C 321-94) tests was 288 psi (2 MPa). Based on the type of failure and the bonding strength measured, bonding strength with wet clay brick was good.

6. CONCLUSIONS

A combination of laboratory tests was used to evaluate the performance of Epoxytec Uroflex (two systems) for coating dry and wet concrete and clay bricks for 6 months. Based on the test results following observations are advanced.

(1) All (100%) the dry coated concrete and wet coated concrete passed the holiday-chemical resistance tests up to six months.

(2) All the Epoxytec Uroflex coated clay bricks (dry and wet) with and without holidays passed the chemical resistant test up to 6 months (100% passed).

(3) Epoxytec Uroflex coating had good bonding strength with wet and dry concrete and clay brick. Most of the bonding test failures were in the substrate (Type 1).

7. REFERENCES

[1] Annual Book of ASTM Standards (1995), Vol. 06.01, Paints-Tests for Formulated Products and Applied Coatings, ASTM, Philadelphia, PA.

[2] Annual Book of ASTM Standards (1995), Vol. 04.05, Chemical Resistant Materials; Vitrified Clay, Concrete, Fiber-Cement Products; Mortar; Masonry, ASTM, Philadelphia, PA.

[3] EPA (1974), "Sulfide Control in Sanitary Sewerage System", EPA 625/1-74-005, Cincinnati, Ohio.

[4] EPA (1985), "Odor and Corrosion Control in Sanitary Sewerage System and Treatment Plants", EPA 625/1-85/018, Cincinnati, Ohio.

[5] Kienow, K. and Cecil Allen, H. (1993). "Concrete Pipe for Sanitary Sewers Corrosion Protection Update," Proceedings, Pipeline Infrastructure II, ASCE, pp. 229-250.

[6] Liu, J., and Vipulanandan, C. (2005) "Tensile Bonding Strength of Epoxy Coatings to Concrete Substrate," Cement and Concrete Research, Vol. 35, pp.1412-1419, 2005.

[7] Liu, J., and Vipulanandan, C. (2004) "Long-term Performance of Epoxy Coated Clay Bricks in Sulfuric Acid," Journal of Materials in Engineering, ASCE, Vol. 16, No. 4, pp.349-355, 2004.

[8] Mebarkia, S., and Vipulanandan, C. “Mechanical properties and water diffusion in polyester polymer concrete”, Journal of Engineering Mechanics 121 (12) (1999) 1359-1365.

[9] Redner, J.A., Randolph, P. Hsi, and Edward Esfandi (1992), "Evaluation of Protective Coatings for Concrete" County Sanitation District of Los Angeles County, Whittier, CA.

[10] Redner, J.A., Randolph, P. Hsi, and Edward Esfandi (1994), "Evaluating Coatings for Concrete in Wastewater facilities: Update," Journal of Protective Coatings and Linings, December 1994, pp. 50-61.

[11] Soebbing, J. B., Skabo, Michel, H. E., Guthikonda, G. and Sharaf, A.H. (1996), "Rehabilitating Water and Wastewater Treatment Plants," Journal of Protective Coatings and Linings, May 1996, pp. 54-64.

[12] Vipulanandan, C., Ponnekanti, H., Umrigar, D. N., and Kidder, A. D. (1996), "Evaluating Coatings for Concrete Wastewater Facilities," Proceedings, Fourth Materials Congress, American Society of Civil Engineers, Washington D.C., November 1996, pp. 851-862.

[13] Vipulanandan, C. and Liu, J. (2005)"Performance of Polyurethane-Coated Concrete in Sewer Environment," Cement and Concrete Research, Vol. 35, pp.1754-1763, 2005.

APPENDIX: A

Behavior of Cement Concrete, Clay Brick and Coating

Summary

In order to ensure the quality, the concrete (cylinders and blocks) and clay bricks used in this study were tested and the results are summarized in this section.

A. 1. *Unit Weight and Pulse Velocity*

The concrete and clay brick specimens used in this coating study characterized based on their unit weight and pulse velocity..

Concrete: The variation of pulse velocity with unit weight is shown in Fig. A1. The unit weight of concrete specimens varied between 138 pcf (21 kN/m^3) and 149 pcf (23 kN/m^3). The pulse velocity varied from 12,600 ft/sec to 16,000 ft/sec. There was no direct correlation between the pulse velocity and unit weight of concrete. The variation of pulse velocity was normally distributed (Fig. A1(b)).

Clay Brick: The variation of pulse velocity with unit weight is shown in Fig. A2. The unit weight of clay brick specimens varied between 129 pcf (20 kN/m^3) and 143 pcf (22 kN/m^3). The pulse velocity varied from 800 ft/sec to 10,500 ft/sec. There was no direct correlation between the pulse velocity and unit weight of concrete. The variation of pulse velocity was normally distributed (Fig. A2(b)).

Coating: The unit weight of coating varied from 62.6 pcf to 64.4 pcf with an average of 63.5 pcf with a coefficient of variation of 0.96%. The pulse velocity varied from 6930 ft/sec to 7285 ft/sec with an average of 7121 ft/sec with a coefficient of variation of 1.6% (Table A6).

A. 2. *Chemical Resistance*

Concrete: Results are summarized in Tables A1 and A2 for concrete cylinders dry and wet respectively. Dry concrete cylinder partially submerged (50%) in water showed continuous increase in weight up to 0.4% in sixty days. The wet concrete in water showed a 0.1%

increase in weight in 60 days. Weight loss and visible corrosion was observed in the dry and wet concrete specimens in the sulfuric acid solution (pH = 1)..

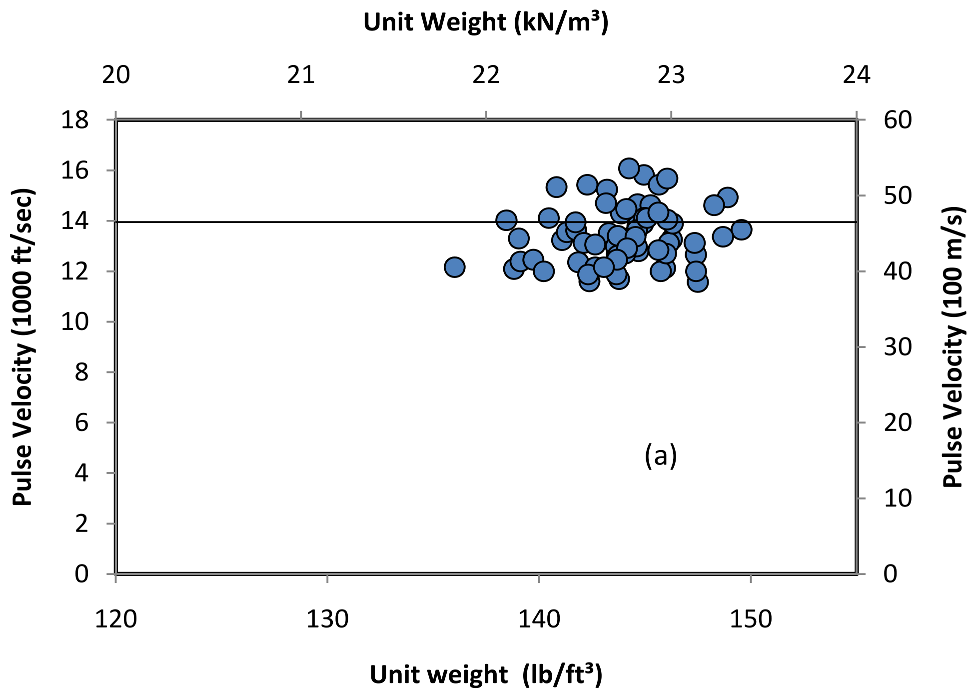
Clay Bricks: Results are summarized in Tables A3 and A4 for dry and wet clay brick respectively. Dry bricks in water and acids showed similar gain in weight of over 10%. No visible damage in bricks were observed. Wet bricks showed much smaller weight gain as compared to the dry bricks. Weight increase was not observed with further soaking.

Coating: Specimens immersed in water for 10 days showed no gain in weight

A. 3. *Strength*

Concrete: Compressive and flexural strength of dry and wet concrete are summarized in Table A5 in Appendix A. The minimum compressive strength of 28 days water cured concrete was 4100 psi (28 MPa) and the flexural strength was 1065 psi (7.6 MPa).

Clay Brick: Flexural strength of dry and wet clay bricks are summarized in Table A5 in Appendix A. The average flexural strength was 1136 psi and 932 psi for wet dry and wet clay bricks. The flexural strength is important for bonding test CIGMAT CT-3 (Modified ASTM C321-94).



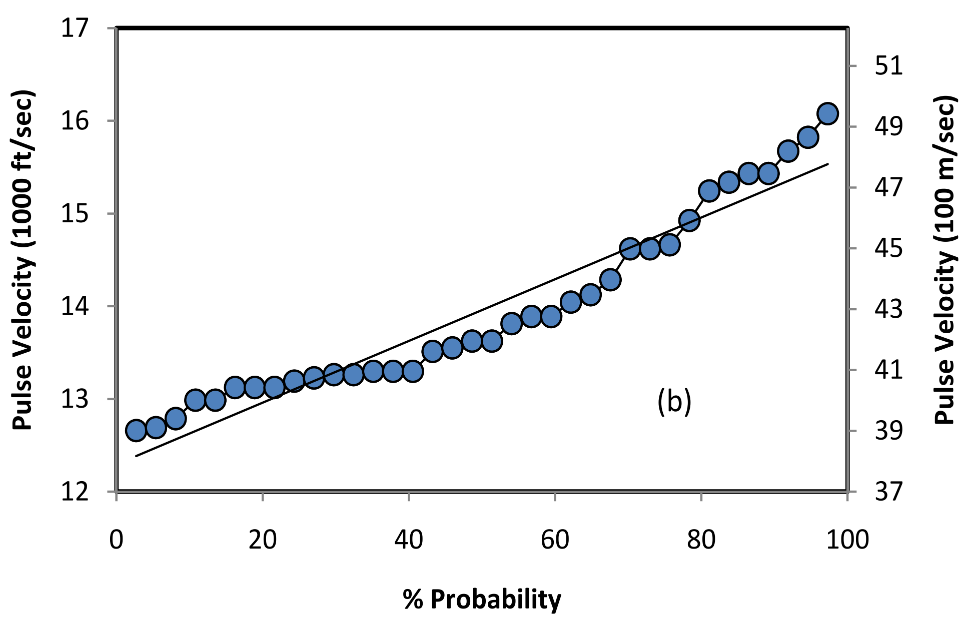


Figure A1. Quality Control for Concrete Brick Specimens (a) Pulse Velocity Versus Unit Weight and (b) Distribution of Pulse velocity

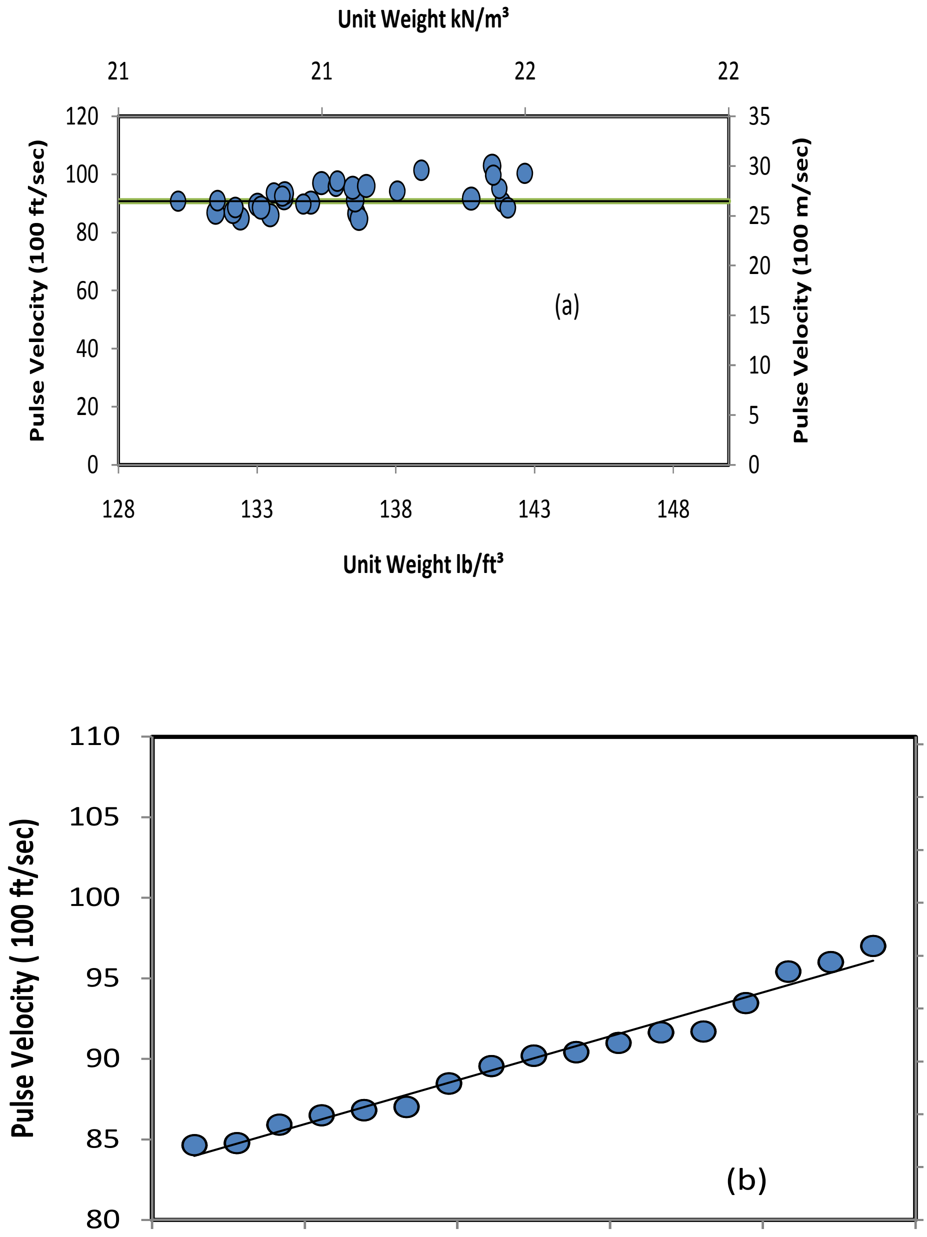


Figure A2. Quality Control for Clay Brick Specimens (a) Pulse Velocity Versus Unit Weight and (b) Distribution of Pulse velocity

Table A1. Results from Chemical Attack Test* on Dry Concrete (CIGMAT CT-1: No Holiday)

Concrete	Immersion Time (days)	Weight Change (%)		Remarks
		DI Water (pH= 6)	H_2SO_4 Solution (pH = 1)	
Dry	10	0.14	0.12	Similar weight change.
	30	0.27	0.32	Similar weight change
	60	0.38	-0.48	Weight loss in acid solution
Remarks	Tested up to 2 months	Total weight change is 0.38 %.	Total weight change is - 0.48%.	Weight loss in H_2SO_4 Solution in 60 days indicates the corrosivity..

*50 % of Specimen was submerged in liquid

Table A2. Results from Chemical Attack Test* on Wet Concrete (CIGMAT CT-1: No Holiday)

Concrete	Immersion Time (days)	Weight Change (%)		Remarks
		DI Water (pH= 6)	H_2SO_4 Solution (pH = 1)	
Wet	10	0.06	0.11	Less weight gain in water.
	30	0.09	0.31	Less weight gain in water.
	60	0.11	-0.52	Weight loss in acid solution
Remarks	Tested up to 2 months	Total weight change is 0.11 %.	Total weight change is -0.52 %.	Weight loss in H_2SO_4 Solution in 60 days indicates the corrosivity..

Table A3. Results from Chemical Attack Test* on Dry Clay (CIGMAT CT-1: No Holiday)

Clay	Immersion Time (days)	Weight Change (%)		Remarks
		DI Water (pH= 6)	H_2SO_4 Solution (pH = 1)	
Dry	10	9	8.3	Similar weight change
	30	12	13.5	Similar weight change
	60	13	15	Similar weight change
Remarks		Total weight change is 13 %.	Total weight change is 15 %.	Similar weight change in water ans acid solution

*50 % of Specimen was submerged in liquid

Table A4. Results from Chemical Attack Test* on Wet Clay (CIGMAT CT-1: No Holiday)

Clay	Immersion Time (days)	Weight Change (%)		Remarks
		DI Water (pH= 6)	H_2SO_4 Solution (pH = 1)	
Wet	10	0.18	0.25	Slightly more weight change in acid solution
	30	0.32	0.43	Slightly more weight change in acid solution
	60	0.40	0.52	Slightly more weight change in acid solution
Remarks		Total weight change is 0.4 %.	Total weight change is 0.52 %.	Slightly more weight change in acid solution

*50 % of Specimen was submerged in liquid

Table A5. Minimum and Maximum Strengths of Concrete Cylinders, Blocks and Clay Bricks

Materials	Curing Time (days)	Compressive Strength (psi) Wet	Compressive Strength (psi) Dry	Flexural Strength (psi) Dry	Flexural Strength (psi) Wet
Concrete Cylinder (No. Specimens)	28	5893 (2)	4099 (2)	Not Applicable	Not Applicable
Concrete Block (No. Specimens)	28	Not Applicable	Not Applicable	1065 (2)	1167 (2)
Clay Brick (No. Specimens)	N/A	Not Applicable	Not Applicable	1136 (2)	932 (2)
Remarks	Concrete cured for 28 days.	Information For quality Control	Information For quality Control	Related to CIGMAT CT-3 (modified ASTM C321-94) Bonding Test	Related to CIGMAT CT-3 (modified ASTM C321-94) Bonding Test

Table A6. Properties of Coating Samples (Uroflex)

Specimen	Unit Weight (pcf)	Pulse Velocity (ft/sec)
1	63.8	7140
2	63.1	7106
3	64.4	6930
4	63.6	7123
5	63.5	7142
6	62.6	7285
Average	63.5	7121
Standard Deviation	0.61	113.5
Coefficient of Variation (COV)	0.96%	1.6%

APPENDIX: B

Laboratory Test: Holiday Test
(CIGMAT CT-1 (Modified ASTM G 20-88)

Summary: Sulfuric Acid Resistance

Total Concrete Cylinders = 20 **Total Clay Bricks = 20**

In order to evaluate the performance of Uroflex, coated concrete cylinders and clay bricks were tested with and without holidays in water and sulfuric acid solution (pH=1). Performance of Uroflex was evaluated over a period of six months from April 2009 to October 2009 in this study. Total of 20 coated concrete specimens and 20 coated clay brick specimens were tested. The results are summarized in Tables B1 through B6.

Epoxytec Uroflex (Dry Coated)
Concrete

One month (30 days): All the specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solution (Table B.1)

Six months (180 days): All the specimens passed the test. Discoloration (DC) was observed, in the lower part of the specimens (liquid phase) and partially in the upper part of the specimens (vapor phase), immersed in sulfuric acid solution (pH=1) (Table B.3).

Clay Brick

One month: All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Six months: All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Epoxytec Uroflex (Wet Coated)

<u>Concrete</u>

One month (30 days): All the specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solution (Table B.2)

Six months (180 days): All the specimens passed the test. Discoloration (DC) was observed, in the lower part of the specimens (liquid phase) and partially in the upper part of the specimens (vapor phase), immersed in sulfuric acid solution (pH=1) (Table B.4).

<u>Clay Brick</u>

One month: All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Six months: All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Rating Criteria for Holiday Test Results

Pass (P): No visible blister. No discoloration. No cracking
Pass with Blister (PB): Visible blister (very small). No discoloration. No cracking
Blister (B): Visible blister up to one inch in diameter. No discoloration. No cracking
Failure (F): Blister with diameter greater than one inch and/or cracking of coating at the holiday
Discoloration (DC): Change in color of the coating

Table B.1 Holiday Test Results for Uroflex Coated Concrete (Dry) after One Month of Immersion CIGMAT CT-1 (Modified ASTM G 20-88)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Dry	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4(100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 30 days of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

Table B2 Holiday Test Results for Uroflex Coated Concrete (Wet) after One Month of Immersion CIGMAT CT-1 (Modified ASTM G20-88)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Wet	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (50/50/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 30 days of immersion	100% Pass	100% Pass		All passed.

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

Table B.3 Holiday Test Results for Uroflex Coated Concrete (dry) after Six Months of Immersion CIGMAT CT-2 (Modified ASTM G 20-88)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Dry	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 180 days of immersion	100% Pass	100% Pass		All passed.

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

Table B.4 Holiday Test Results for Uroflex Coated Concrete (Wet) after Six Months of Immersion CIGMAT CT-2 (Modified ASTM G20-88)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Wet	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/00)	Total of 10 specimens tested
Remarks	After 180 days of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

Table B5. Holiday Test Results for Uroflex Coated Clay Brick (Dry) after One (1) Month of Immersion CIGMAT CT-1 (Modified ASTM G20-88)

Clay	Holiday	Medium and Rating (No. of Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Dry	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After one month of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB= Pass with Blister.

Table B6. Holiday Test Results for Uroflex Coated Clay Brick (Wet) after One (1) Month of Immersion CIGMAT CT-1 (Modified ASTM G20-88)

Clay	Holiday	Medium and Rating (No. of Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Wet	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After one (1) month of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

Table B7. Holiday Test Results for Uroflex Coated Clay Brick (Dry) after Six (6) Month of Immersion CIGMAT CT-1 (Modified ASTM G20-88)

Clay	Holiday	Medium and Rating (No. of Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	H_2SO_4		
Dry	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/6)	Total of 10 specimens tested
Remarks	After six months of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB= Pass with Blister.

Table B8. Holiday Test Results for Uroflex Coated Clay Brick (Wet) after Six (6) Month of Immersion CIGMAT CT-1 (Modified ASTM G 20-88)

Clay	Holiday	Medium and Rating (No. of Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	H_2SO_4		
Wet	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After six months of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

APPENDIX: B

Laboratory Test: Holiday Test
(CIGMAT CT-1 (Modified ASTM G 20-88)

Summary: Sulfuric Acid Resistance

Total Concrete Cylinders = 20 Total Clay Bricks = 20

In order to evaluate the performance of Uroflex, coated concrete cylinders and clay bricks were tested with and without holidays in water and sulfuric acid solution (pH=1). Performance of Uroflex was evaluated over a period of six months from April 2009 to October 2009 in this study. Total of 20 coated concrete specimens and 20 coated clay brick specimens were tested. The results are summarized in Tables B1 through B6.

Epoxytec Uroflex (Dry Coated)
Concrete

One month (30 days): All the specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solution (Table B.1)

Six months (180 days): All the specimens passed the test. Discoloration (DC) was observed, in the lower part of the specimens (liquid phase) and partially in the upper part of the specimens (vapor phase), immersed in sulfuric acid solution (pH=1) (Table B.3).

Clay Brick

One month: All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Six months: All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Epoxytec Uroflex (Wet Coated)

<u>Concrete</u>

One month (30 days): All the specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solution (Table B.2)

Six months (180 days): All the specimens passed the test. Discoloration (DC) was observed, in the lower part of the specimens (liquid phase) and partially in the upper part of the specimens (vapor phase), immersed in sulfuric acid solution (pH=1) (Table B.4).

<u>Clay Brick</u>

One month: All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Six months: All specimens passed the test. Change in color of the coating was observed on the portion of the specimens submerged in sulfuric acid solutions.

Rating Criteria for Holiday Test Results

Pass (P): No visible blister. No discoloration. No cracking
Pass with Blister (PB): Visible blister (very small). No discoloration. No cracking
Blister (B): Visible blister up to one inch in diameter. No discoloration. No cracking
Failure (F): Blister with diameter greater than one inch and/or cracking of coating at the holiday
Discoloration (DC): Change in color of the coating

Table B.1 Holiday Test Results for Uroflex Coated Concrete (Dry) after One Month of Immersion CIGMAT CT-1 (Modified ASTM G 20-88)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Dry	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4(100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 30 days of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

Table B2 Holiday Test Results for Uroflex Coated Concrete (Wet) after One Month of Immersion CIGMAT CT-1 (Modified ASTM G20-88)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Wet	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (50/50/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 30 days of immersion	100% Pass	100% Pass		All passed.

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

Table B.3 Holiday Test Results for Uroflex Coated Concrete (dry) after Six Months of Immersion CIGMAT CT-2 (Modified ASTM G 20-88)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Dry	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After 180 days of immersion	100% Pass	100% Pass		All passed.

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

Table B.4 Holiday Test Results for Uroflex Coated Concrete (Wet) after Six Months of Immersion CIGMAT CT-2 (Modified ASTM G20-88)

Concrete	Holiday	Medium and Rating (Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Wet	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/00)	Total of 10 specimens tested
Remarks	After 180 days of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

Table B5. Holiday Test Results for Uroflex Coated Clay Brick (Dry) after One (1) Month of Immersion CIGMAT CT-1 (Modified ASTM G20-88)

Clay	Holiday	Medium and Rating (No. of Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Dry	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After one month of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB= Pass with Blister.

Table B6. Holiday Test Results for Uroflex Coated Clay Brick (Wet) after One (1) Month of Immersion CIGMAT CT-1 (Modified ASTM G20-88)

Clay	Holiday	Medium and Rating (No. of Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	3% H_2SO_4		
Wet	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After one (1) month of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

Table B7. Holiday Test Results for Uroflex Coated Clay Brick (Dry) after Six (6) Month of Immersion CIGMAT CT-1 (Modified ASTM G20-88)

Clay	Holiday	Medium and Rating (No. of Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	H_2SO_4		
Dry	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/6)	Total of 10 specimens tested
Remarks	After six months of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB= Pass with Blister.

Table B8. Holiday Test Results for Uroflex Coated Clay Brick (Wet) after Six (6) Month of Immersion CIGMAT CT-1 (Modified ASTM G 20-88)

Clay	Holiday	Medium and Rating (No. of Specimens)		Total No. %(P/B/F)	Remarks
		DI Water	H_2SO_4		
Wet	No Holiday	P(2)	P(2)	4 (100/0/0)	Pass
	1/8 inch	P(2)	P(2)	4 (100/0/0)	Pass
	1/2 inch	---	P(2)	2 (100/0/0)	Pass
Total No. %(P/B/F)		4 (100/0/0)	6 (100/0/0)	10 (100/0/0)	Total of 10 specimens tested
Remarks	After six months of immersion	100% Pass	100% Pass		All passed

P=Pass; B=Blister; F=Failure; PB=Pass with Blister.

APPENDIX: C

Laboratory Test: Bonding Test
(CIGMAT CT-2 (Modified ASTM D 4541-85) and
CIGMAT CT-3 (Modified ASTM C 321-94)

Summary: Tensile Bonding Strength

Total CIGMAT CT-2 Tests =24　　**Total CIGMAT CT-3 Tests = 24**

Bonding strengths of Epoxytech Inc. Uroflex coating on dry and wet concrete and clay brick were determined according to CIGMAT CT-2 (modified ASTM D 4541-85) and CIGMAT CT-3 (modified ASTM C 321-94) testing methods. All the coated specimens were cured under water. Both dry and wet concrete and clay brick specimens were coated to simulate the various field conditions. Performance of Epoxytec Uroflex coating was evaluated starting April, 2009 and the results are included in this report. Total of 24 bonding tests with concrete specimens and 24 with clay brick specimens have been performed. The results are summarized in Tables C2 through C9 with the type of failure.

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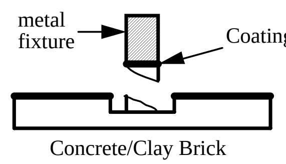
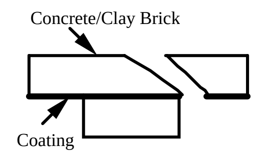
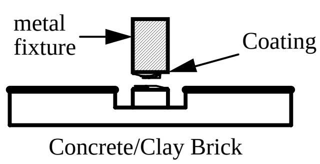
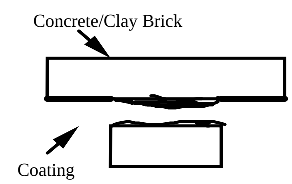
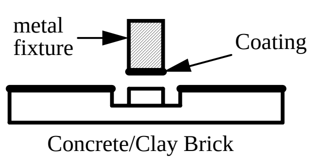
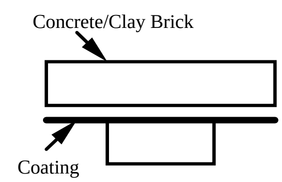
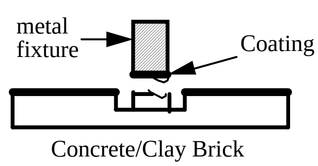
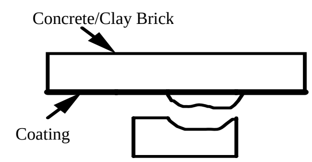
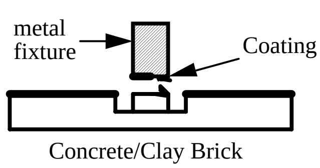
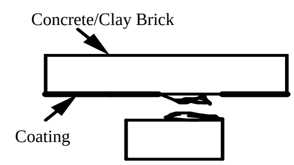
Failure Types

All the potential failure types generally encountered in the bonding tests (modified ASTM D 4541 and ASTM C 321) are listed in Table C1. Type-1 failure is substrate failure (Table C1). This is the most desirable result if the bonding strength is quite high (generally in the range 6% to 12% of the substrate compressive strength). In Type-2 failure (Table C1), the coating fails. Type-3 failure is bonding failure where failure occurred between the coating and substrate. Type-4 and Type-5 are combined failures. Type-4 failure is the combination of bonding and substrate failure where the failure occurs in the substrate and on the interface of the coating and the substrate. This indicates that the adhesive strength is comparable with the tensile strength of substrate. Type-5 failure (Table C1) is coating and bonding failure where the failure occurs due to low cohesive and adhesive strength of the coating.

Table C1. Bonding Failure Types of CIGMAT CT-2 (modified ASTM D 454) and CIGMAT CT-3 (modified ASTM C 321) Tests

Failure Type	**Description**	**CIGMAT CT-2 Test (Modified ASTM D 4541)**	**CIGMAT CT-3 Test (Modified ASTM C 321)**
Type 1	Substrate Failure		
Type 2	Coating Failure		
Type 3	Bonding Failure		
Type 4	Bonding and Substrate Failure		
Type 5	Bonding and Coating Failure		

Uroflex (Dry Coating)

(i) Concrete

CIGMAT CT-2 (modified ASTM D 4541-85): A total of 6 laboratory tests were performed. 100% Type-1(Fig. C1) failure was observed. The Average bonding strength from all the tests performed was 296 psi (2 MPa) (Table C2).

CIGMAT CT-3 (modified ASTM C 321-94): A total of 6 tests were performed. Test results are summarized in Table C6 and Figures C4, C6 and C8. All failures were Type-1. Average bonding strength from all the laboratory tests was 235 psi (1.6 MPa) (Table C6).

Summary: Type of test did not influence the mode of failure.. Type-1 failure was observed during CIGMAT CT-2 (modified ASTM D 4541) test. CIGMAT CT-3 (modified ASTM C 321-94) produced Type-1 failure. The average bonding strengths from CIGMAT CT-2 (modified ASTM D4541) tests was 296 psi (2 MPa) and from CIGMAT CT-3 (modified ASTM C 321-94) tests was 235 psi (1.6 MPa). Bonding strength with dry concrete was good.

(ii) Clay Brick

CIGMAT CT-2 (modified ASTM D 4541-85): A total of 6 tests were performed. Type-1 (68%), Type-3 (16%) and Type-5 (16%) failures were observed. The average bonding strength from all the tests was 348 psi (2.4 MPa) (Table C4).

CIGMAT CT-3 (modified ASTM C 321-94): A total of 6 tests were performed. Type 1 failure (100%) was observed in the test. Test results are summarized in Table C8 and Figures C4, C6 and C8. And the average bonding strength was 316 psi (2.1 MPa) (Table C8).

Summary: Type of test had minimal influence the dominant mode of failure (Type-1) . Type-1 (68%), Type-3 (16%) and Type-5 (16%) failures were observed during CIGMAT CT-2 (modified ASTM D 4541) test. CIGMAT CT-3 (modified ASTM C 321-94) produced 100% Type-1 failure. The average bonding strengths from ASTM D 4541 tests was 348 psi (2.4 MPa) and from ASTM C 321-94 tests was 316 psi (2.1 MPa). Bonding strength with dry clay brick was good.

Uroflex (Wet Coating)

(i) Concrete

CIGMAT CT-2 (modified ASTM D 4541-85): A total of 6 laboratory tests were performed. All the failures were Type-4 (100%). Average bonding strength from this test was 254 psi (1.7 MPa) (Table C3).

CIGMAT CT-3 (modified ASTM C 321-94): A total of 6 tests were performed. Both Type-1 (84%) and Type-4 (16%) failures were observed. Test results are summarized in Table C7 and Figures C5, C7 and C9. Average bonding strength from laboratory tests was 240 psi (1.6 MPa) (Table C7).

Summary: The average bonding strengths from CIGMAT CT-2 (modified ASTM D 4541) tests was 254 psi (1.7 MPa) and from CIGMAT CT-3 (modified ASTM C 321-94) tests was 240 psi (1.6 MPa). Based on the type of failure and the bonding strength measured, bonding strength with wet concrete was good.

(ii) Clay Brick

CIGMAT CT-2 (modified ASTM D 4541-85): A total of 6 tests were performed. All failures were Type-1 (100%). The average bonding strength was 322 psi (2.2 MPa) (Table C5).

CIGMAT CT-3 (modified ASTM C 321-94: A total of 6 tests were performed. 100% Type 1 failure was observed in the test. Test results are summarized in Table C9 and Figures C5, C7 and C9. The average bonding strength was 288 psi (2 MPa) (Table C9).

Summary: Type of test did not influence the type of failure. All failures were. Type-1. The average bonding strengths from CIGMAT CT-2 (modified ASTM D 4541) tests was 322 psi (2.2 MPa) and from CIGMAT CT-3 (modified ASTM C 321-94) tests was 288 psi (2 MPa). Based on the type of failure and the bonding strength measured, bonding strength with wet clay brick was good.

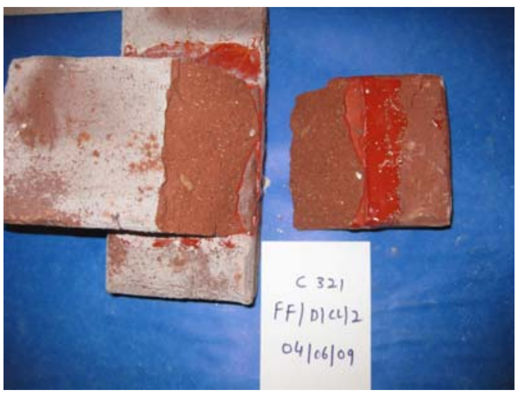
(a) Wet Concrete

(b) Dry Concrete

Figure C1. Type-4 and Type-1 failures during ASTM D4541-85 test with (a)Wet and (b) Dry Concrete respectively.

(a) Dry Uroflex coated concrete (b) Wet Uroflex coated concrete

Figure C2. Bonding failure (Type-1 Failure) during ASTM C 321-94 test (a) Dry Coated Concrete and (b) Wet Coated Concrete



(a) Dry Uroflex coated clay brick (b) Wet Uroflex coated clay brick

Figure C3. Bonding failure (Type-1 Failure) during ASTM C 321-94 test (a) Dry Coated Clay Brick and (b) Wet Coated Clay Brick

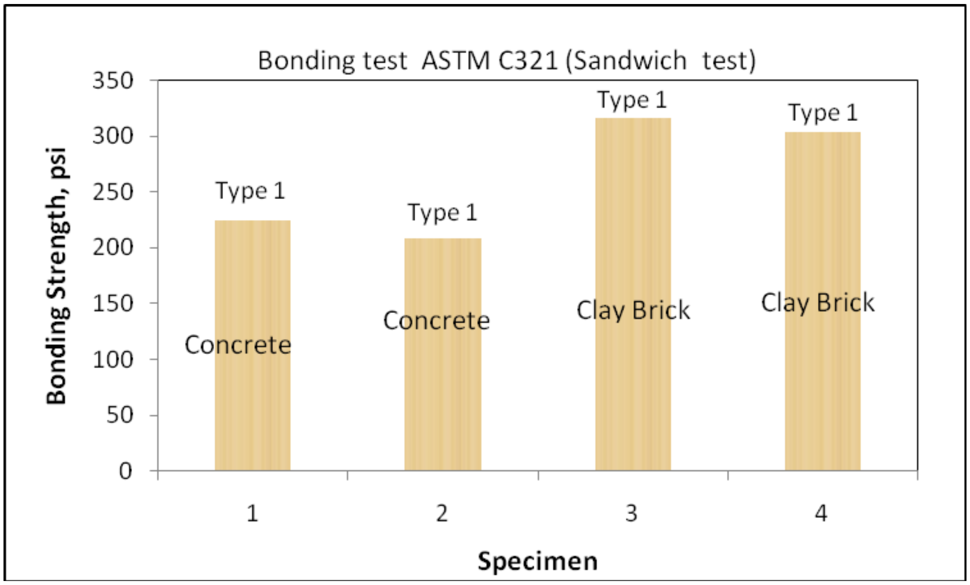


Figure C4. Bonding strength and types of failures of dry Epoxytec Uroflex coated concrete and clay bricks after one month of the immersion test during CIGMAT CT-3 (ASTM C 321-94) test.

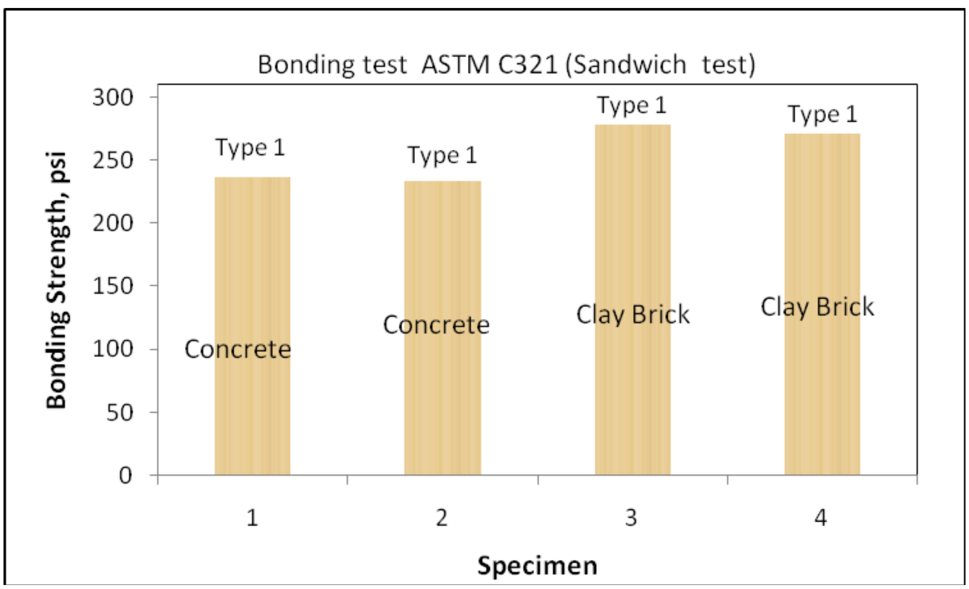


Figure C5. Bonding strength and types of failures of wet Epoxytec Uroflex coated concrete and clay bricks after one month of the immersion test during CIGMAT CT-3 (modified ASTM C 321) test

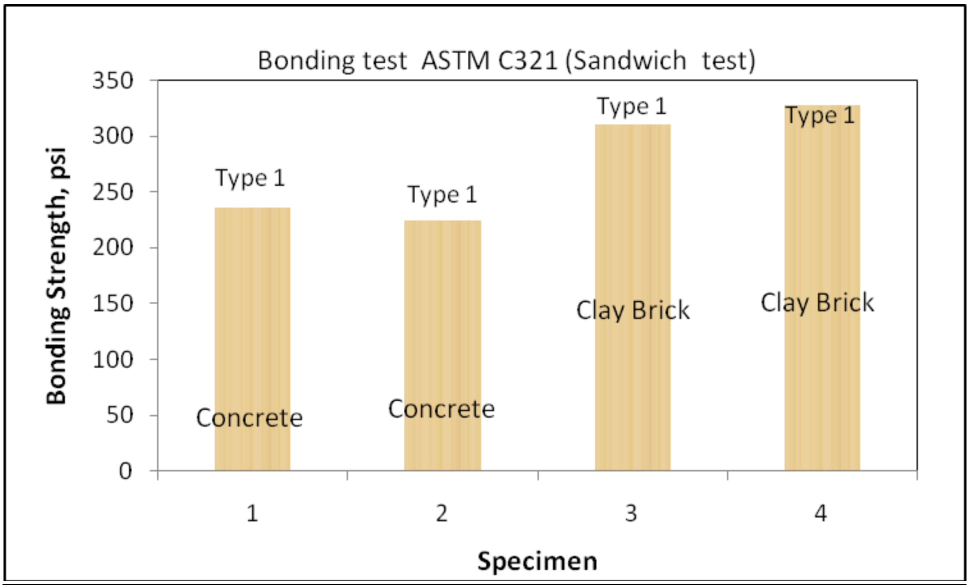


Figure C6. Bonding strength and types of failures of dry Epoxytec Uroflex coated concrete and clay bricks after three months of the immersion test during CIGMAT CT-3 (modified ASTM C 321) tests.

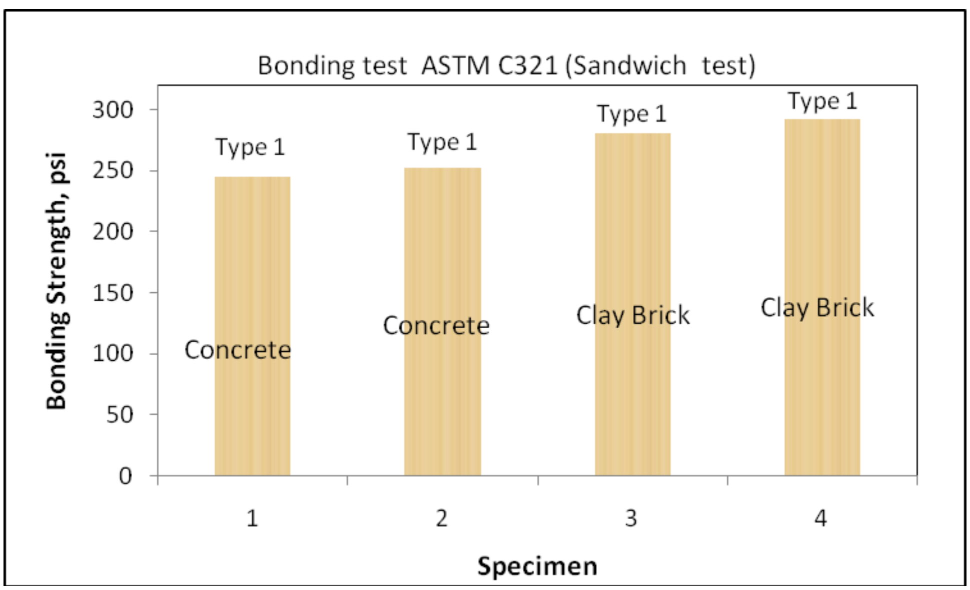


Figure C7. Bonding strength and types of failures of wet Epoxytec Uroflex coated concrete and clay bricks after three months of the immersion test during CIGMAT CT-3 (modified ASTM C 321) tests.

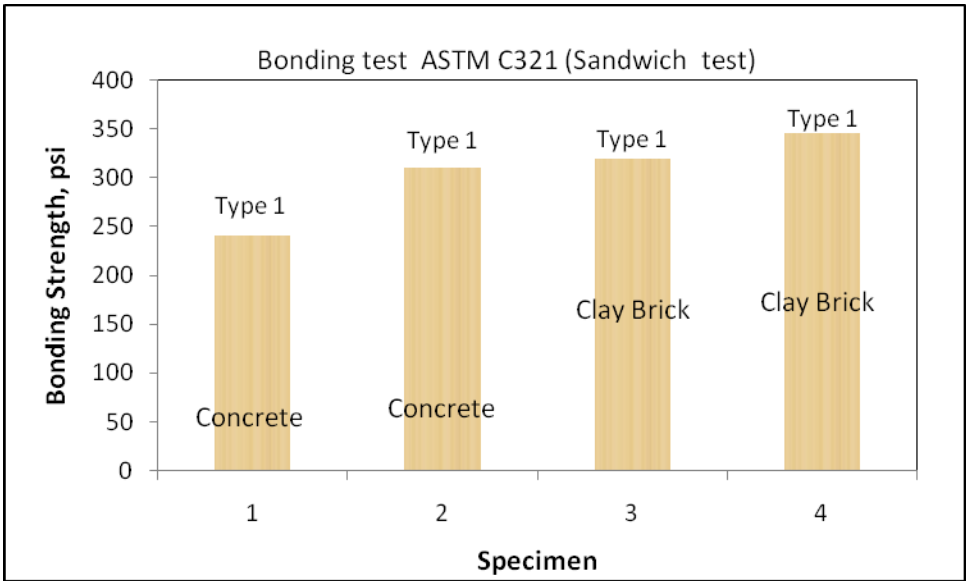


Figure C8. Bonding strength and types of failures of Dry Epoxytec Uroflex coated concrete and clay bricks after six months of the immersion test during CIGMAT CT-3 (modified ASTM C 321) tests.

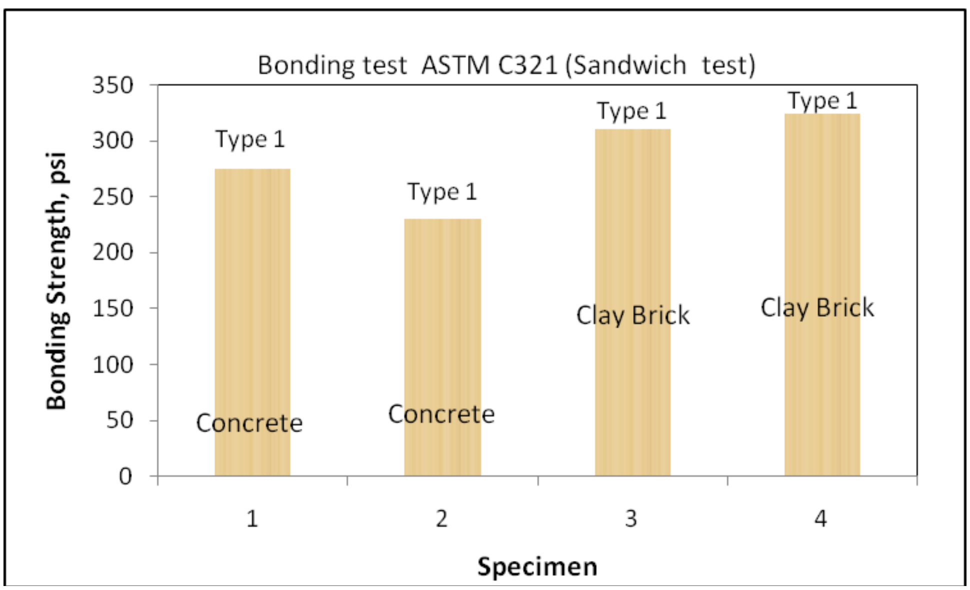


Figure C9. Bonding strength and types of failures of Wet Epoxytec Uroflex coated concrete and clay bricks after six months of the immersion test during CIGMAT CT-3 (modified ASTM C 321) tests

Table C2. Bonding Strength of Uroflex with Dry Concrete CIGMAT CT-2 (modified ASTM D 4541)

Concrete	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Dry	30	XX					228
	60	XX					284
	180	X X					375
Total No. (% Failure)		6 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	Total of 6 tests.
Remarks	Up to six (6) months	Good bonding strength	None	None	None	None	100% Types 1 failure. Average bonding strength was 296 psi (2 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 C3. Bonding Strength Uroflex with Wet Concrete CIGMAT CT-2 (modified ASTM D 4541)

Concrete	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Wet	30				XX		164
	60				XX		252
	180				XX		348
Total No. (% Failure)		0 (0%)	0 (0%)	0 (0%)	6 (100%)	0 (0%)	Total of 6 tests.
Remarks	Up to six (6) months	None	None	None	Above average bonding strength	None	100% Types 4 failure. Average bonding strength was 254 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

Table C4. Bonding Strength of Uroflex with Dry Clay Brick CIGMAT CT-2 (modified ASTM D 4541)

Clay	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Dry	30			X		X	280
	60	XX					340
	180	XX					426
Total No. (% Failure)		4 (68%)	0 (0%)	1 (16%)	0 (0%)	1 (16%)	Total of 6 tests.
Remarks	Up to six (6) months	Good bonding strength	None	Poor bonding strength	None	Below average bonding strength	Type 1,3 and 5 failures. Average bonding strength was 348 psi (2.4 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 C5. Bonding Strength of Uroflex with Wet Clay Brick CIGMAT CT-2 (modified ASTM D 4541)

Clay	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Wet	30	XX					269
	60	XX					325
	180	XX					373
Total No. (% Failure)		6 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	Total of 6 tests.
Remarks	Up to six (6) months	Good bonding strength	None	None	None	None	100% Types 1 failure. Average bonding strength was 322 psi (2.2 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 C6. Bonding Strength of Uroflex with Dry Concrete CIGMAT CT-3 (modified ASTM C 321)

Concrete	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Dry	30	XX					208
	60	XX					224
	180	XX					275
Total No. (% Failure)		6 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	Total of 6 tests.
Remarks	Up to six (6) months	Good bonding strength	None	None	None	None	100% Type 1 failure. Average bonding strength was 235 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

Table C7. Bonding Strength of Uroflex with Wet Concrete CIGMAT CT-3 (modified ASTM C 321)

Concrete	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Wet	30	X			X		233
	60	XX					235
	180	XX					252
Total No. (% Failure)		5 (84%)	0 (0%)	0 (0%)	1 (16%)	0 (0%)	Total of 6 tests.
Remarks	Up to six (6) months	Good bonding strength	None	None	Above average bonding strength	None	Type 1 and 4 failures. Average bonding strength was 240 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

Table C8. Bonding Strength of Uroflex with Dry Clay Brick CIGMAT CT-3 (modified ASTM C 321)

Concrete	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Dry	30	XX					304
	60	XX					316
	180	XX					328
Total No. (% Failure)		6 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	Total of 6 tests.
Remarks	Up to six (6) months	Good bonding strength	None	None	None	None	100% Type 1 failure. Average bonding strength was 316 psi (2.1 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 C9. Bonding Strength of Uroflex with Wet Clay Brick CIGMAT CT-3 (modified ASTM C 321)

Concrete	Curing Time (days)	Failure Modes					Failure Strength (psi)
		Type 1	Type 2	Type 3	Type 4	Type 5	
Wet	30	XX					271
	60	XX					278
	180	XX					316
Total No. (% Failure)		6 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	Total of 6 tests.
Remarks	Up to six (6) months	Good bonding strength	None	None	None	None	100% Type 1 failure. Average bonding strength was 288 psi (2 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.

APPENDIX: D

Vendor Data Sheet

Epoxytec Uroflex™ (Two coat system [three coats when wet- used Epoxytec B2 primer])

Coating- 100% solid urethane modified epoxy
Color- red
Application- roller
Pot life- 40 minutes
Application time- one and one half hours
Mils- 50 (two coats 25 mils each)
Preparation for all dry concrete samples- brush off laitance with non-wire brush (this is the only prep).
Preparation for all dry clay samples- no prep at all.
Preparation for all wet concrete- no prep at all (used Epoxytec B2 Primer)
Preparation for all wet clay samples- no prep at all.
VOC's- none
Clean up- MEK (while curing).