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RESEARCH PROGRAM
INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

Development of a Cost-Effective Concrete Bridge Deck Preservation Program

Volume 2—Final Results and Recommendations

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John P. Lyrenmann, Andrew S. Pollastrini**

SPR-3320 • Report Number: FHWA/IN/JTRP-2016/23 • DOI: 10.5703/1288284316346

RECOMMENDED CITATION

Frosch, R. J., Kreger, M. E., Byl, E. A., Lyrenmann, J. P., & Pollastrini, A. S. (2016). *Development of a cost-effective concrete bridge deck preservation program: Volume 2—Final results and recommendations* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2016/23). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284316346

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ACKNOWLEDGMENTS

The research presented in this document was sponsored by the Indiana Department of Transportation (INDOT) and Purdue University through the Joint Transportation Research Program (JTRP) as contract SPR-3320. The authors would like to thank JTRP, as well as the INDOT Project Administrator, Timothy Wells, and Business Owner, Jeremy Hunter, for their support. The authors would like to express their gratitude to the members of the INDOT Study Advisory Committee for their input and guidance throughout the project: Bill Dittrich, Keith Hoernschemeyer, Jim Mickler, Frank Sailor, Todd Shields, George Snyder, Drew Storey, and Tony Zander. Finally, thanks are extended to the Sika Corporation and BASF for their donation of sealing materials for use in this study.

JOINT TRANSPORTATION RESEARCH PROGRAM

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Print ISBN: 978-1-62260-445-6
ePUB ISBN: 978-1-62260-446-3

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/IN/JTRP-2016/23	**2. Government Accession No.**	**3. Recipient's Catalog No.**

4. Title and Subtitle

Development of a Cost-Effective Concrete Bridge Deck Preservation Program: Volume 2—Final Results and Recommendations

5. Report Date
July 2016

6. Performing Organization Code

7. Author(s)

Robert J. Frosch, Michael E. Kreger, Emily A. Byl, John P. Lyrenmann, Andrew S. Pollastrini

8. Performing Organization Report No.

FHWA/IN/JTRP-2016/23

9. Performing Organization Name and Address
Joint Transportation Research Program
Purdue University
550 Stadium Mall Drive
West Lafayette, IN 47907-2051

10. Work Unit No.

11. Contract or Grant No.
SPR-3320

12. Sponsoring Agency Name and Address
Indiana Department of Transportation
State Office Building
100 North Senate Avenue
Indianapolis, IN 46204

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.

16. Abstract

The deterioration of bridge decks has been identified as a major problem in Indiana. The primary cause of this deterioration is salt water ingress from the application of deicing salts during the winter. Deicing chemicals placed on the road mix with water and enter the deck through cracks and the pore structure of the concrete. This results in corrosion of the reinforcing steel and scaling of the surface, which leads to a shortened bridge deck life and costly deck replacement. The objective of this study is to investigate potentially effective and economic bridge deck preservation methods to significantly extend the service life of bridge decks, and as a result, extend the life of bridge structures in the State of Indiana. The research is presented in two volumes. Volume 1 focuses on the development and implementation of the experimental program. A survey of State Departments of Transportation identified the types of bridge deck preservation programs that are currently in use, the methods that they have employed in the past, and the perceived level of success with these programs and methods. A literature review provided information regarding specific products that performed well, characteristics of broader chemical families and their best uses, and other variables that may influence the effectiveness of sealers. The results of the DOT survey and literature review were used to determine the materials and methods to be further investigated in the experimental study. Based on this background, a series of macrocell specimens were constructed, and a salt water exposure regimen was initiated to examine the effectiveness of deck/crack sealer materials and application methods that were identified. Volume 2 presents the results of this study which were developed through the analysis of the recorded electrical activity after 1600 days of exposure followed by autopsy of the specimens. A visual rating scheme was used to assess the specimens during autopsy and to demonstrate the correspondence between the observed severity of corrosion and the recorded electrical activity. In addition, a deck sealer was applied to specimens with preexisting corrosion to evaluate the sealer's effectiveness in slowing the rate of corrosion. The deck sealer products were studied further by correlating both the sealer penetration depth and the chloride penetration profile with the products' effectiveness in resisting corrosion activity. A preliminary field application of crack sealer to an existing bridge deck was completed to evaluate processes, equipment, and other required resources. Finally, recommendations are provided regarding product selection and application to enable cost effective implementation of a bridge deck sealing program across the State of Indiana.

17. Key Words
bridges, bridge deck service life, bridge deck preservation, maintenance, durability, corrosion, macrocell, concrete deck, bridge deck cracking, concrete sealer, deck sealer, crack sealer, deck sealant, crack sealant, crack repair, healer-sealer, penetrating sealer, chloride ingress, water repellent, salt ingress, silane, linseed oil, low viscosity epoxy, methacrylate, depth of penetration

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	169	

Form DOT F 1700.7 (8-69)

EXECUTIVE SUMMARY

DEVELOPMENT OF A COST-EFFECTIVE CONCRETE BRIDGE DECK PRESERVATION PROGRAM: VOLUME 2—FINAL RESULTS AND RECOMMENDATIONS

Introduction

Concrete bridge decks across the state of Indiana have experienced ongoing degradation caused by applications of deicing salts during the winter. Salt water collects on the deck and permeates the concrete through the cracks and the deck surface, allowing chlorides to initiate corrosion of the reinforcing steel. Over time, corrosion of the reinforcement leads to the need for costly deck repairs or even deck replacement prior to the expected service life of the bridge. The use of localized crack sealers and deck surface sealers has the potential of providing a cost-effective method of deck preservation that could be implemented across the state to prolong the life of bridge decks.

The objective of this study is to investigate potentially effective and economic bridge deck preservation methods to significantly extend the service life of bridge decks, and as a result, extend the life of bridge structures in Indiana. A literature review and survey of state departments of transportation were completed to guide the development of the experimental program and construction of the test specimens. The experimental program included continual monitoring of the specimens exposed to a salt water ponding regimen for a period of 1600 days, autopsy of the specimens to correlate observed interior corrosion with measured corrosion activity, and application of a deck sealer to specimens with preexisting corrosion to evaluate the sealer's effectiveness in slowing the rate of corrosion. Deck sealer performance was investigated further by correlating the occurrence of corrosion with sealer penetration depth and chloride penetration profiles. A preliminary field test of sealer applications was also completed to inform the development of field application methods. The research is presented in two volumes. Volume 1 presents the development and implementation of the experimental program while Volume 2 presents the results of the experimental program.

Findings

Volume 1

Based on the literature review and survey, the following findings were developed:

- Both epoxy and methacrylate products have been identified as effective localized crack sealers. Epoxy crack sealers generally are shown to have stronger bond strength and better durability in wider cracks, while methacrylate crack sealers provided better crack penetration particularly for narrower cracks.
- Silicone-based products, such as siloxanes and silanes, have been determined to be high-performing deck surface sealers. Silanes were found to be the most effective in most cases, especially solvent-based products with higher solids content.
- Water-based silane products also performed well as deck sealers and would be useful as a substitute in an environmentally sensitive situation. It is important to note, however, that reapplication of a water-based product may not be effective as water-based products repel themselves wherever traces of the sealer remain from previous applications.
- Linseed oil has been used as a deck sealer with varying success rates.
- Products within the same chemical family have been capable of very different performance; therefore, the specific product used is important.
- If a bridge deck is expected to be exposed to deicing salts, any cracks should be sealed, as well as the full deck surface. Sealing should be completed as soon as possible in the life of the bridge to prevent as much chloride intrusion as possible.
- A variety of methods and materials exist and are in use today for protecting bridge decks. Different states have varying thoughts on the effectiveness of different types of products and whether their use is economically beneficial.
- Both epoxy and methacrylate products are commonly used as crack fillers/sealers and currently are the only products in use by responding states. Silane and linseed oil are the most commonly used deck sealers by responding states. Other preservation approaches include barrier membranes and overlays.

Volume 2

Based on completion of the 1600-day experimental program and the field test, the following findings were developed:

- Sikadur 55 SLV and Dural 335, low-viscosity epoxies, were shown to be effective in reducing corrosion in cracked concrete by as much as 80 to 100%. The methacrylate crack sealer MasterSeal 630 exhibited contradictory performance. It was found that it has the potential to effectively seal cracks; however, its performance in this experimental program may have been sensitive to installation procedures due to its lower viscosity as compared with the epoxies. Furthermore, methacrylate crack sealers have been shown to be more effective in narrower cracks (<0.016 in.) than those investigated in this experimental program.
- The deck sealers MasterProtect H 440 HZ, MasterProtect H 400, and linseed oil were not effective at preventing salt water intrusion in cracked concrete. The use of a deck sealer does not prevent salt water intrusion at cracks; moreover, the deck sealer may actually inhibit evaporation of moisture from the deck, causing even more corrosion than in an unsealed deck.
- The four crack and deck sealer combinations investigated were extremely successful in reducing chloride ingress and preventing corrosion activity for the duration of the experimental program. The only exception to this performance was the varied results of the sealer combination comprised of crack sealer MasterSeal 630 and deck sealer MasterProtect H 440 HZ, which again suggests that MasterSeal 630 may have been sensitive to installation methods.
- Simulation of traffic wear on uncracked concrete with applied deck sealer revealed that the likelihood of corrosion increases as the depth of sealer penetration is abraded over time. Therefore, reapplication of deck sealers over time is warranted.
- Application of a deck sealer to reinforced concrete with preexisting corrosion did not appear to slow the rate of corrosion. This finding was likely due to the presence of surface cracks, which are not effectively sealed by use of a deck sealer alone. However, given the observed effectiveness of applying both a crack and deck sealer to reduce salt water ingress, it is expected that the use of such a sealer combination would effectively slow the rate of preexisting corrosion.
- When installing a two-part epoxy crack sealer, the use of a two-component joint sealer pump such as the model used in

the field test provides an effective and efficient means of crack sealer application.
- Deck sealer application can be accomplished effectively and efficiently by use of a truck-mounted sprayer bar, such as the one developed for the field test.

Implementation

It is recommended that both localized crack sealers and deck surface sealers are used to resist chloride ingress in the deck and to reduce corrosion of the reinforcing steel. First, it is recommended that wide cracks be sealed using epoxy crack sealers (Sikadur 55 SLV or Dural 335) and narrow cracks be sealed using a methacrylate crack sealer (MasterSeal 630). Completion of crack sealing should be followed by application of a deck sealer to prevent/reduce ingress through the deck surface. Although all three deck sealers in this experimental program were shown to be effective, it should be noted that the use of MasterProtect H 440 HZ is no longer permitted in the state of Indiana. It should also be noted that MasterProtect H 400 is a water-based product. While this product can be effective for initial application, it is not recommended for reapplication as water-based products repel themselves wherever penetrating deck sealers remain from previous applications.

To prepare for installation, it is recommended that dust and debris be cleaned from the cracks and the deck surface prior to application of crack sealers and deck sealers. Surface preparation in the form of roughening or sandblasting, however, is not required prior to sealer applications because the preexisting roughness of the bridge deck from surface tining and traffic abrasion allow for sufficient sealer penetration.

To maintain effectiveness of the sealer over time, it is recommended that decks are resealed every 5 years. Traffic abrasion was found to significantly reduce the effectiveness of deck sealers as it removed the layer of protection provided by the sealer. Extended reapplication times may be appropriate for bridges with low traffic volumes. As discussed previously, reapplication of a water-based product (such as MasterProtect H 400) is only effective in locations where the sealer has been removed as water-based products repel themselves wherever traces of the sealer remain from previous applications. For this reason, reapplication using non-water-based sealers is recommended. If a water-based sealer is used, the remaining penetration depth of the previous sealer should be removed through preparation of the surface such as sandblasting to ensure that the full penetration depth of the sealer can be achieved.

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1. INTRODUCTION

1.1 Introduction

Concrete bridge decks across the state of Indiana have experienced ongoing degradation caused by applications of deicing salts during the winter seasons. Salt water collects on the deck and permeates the concrete through the cracks and the deck surface, allowing chlorides to initiate corrosion of the reinforcing steel. Over time, corrosion of the reinforcement leads to the need for costly deck repairs or even deck replacement prior to the expected service life of the bridge. The use of localized crack sealers and deck surface sealers has the potential of providing a cost-effective method of deck preservation that could be implemented across the state to prolong the life of bridge decks.

1.2 Corrosion

When deicing salts are applied to the bridge deck, the salt mixes with the precipitation on the roadway to form a saline solution that penetrates the deck either at crack locations or by seeping through the pore structure of the concrete. The steel reinforcement is protected by a passive layer formed at its surface due to the alkalinity of the surrounding concrete. When salt water reaches the depth of the reinforcing bars, the chloride ions depassivate this protective layer, allowing water and oxygen to cause microcell and/or macrocell corrosion. These types of corrosion involve an oxidation reaction at an anode location from which electrons move through the steel bar to the cathode location. The reduction of oxygen at the cathode produces hydroxyl ions, which flow back to the anode through the water in the pores of the surrounding concrete (Elsener, 2002).

In microcell corrosion, the anode and cathode are both located along the same bar (Figure 1.1). In macrocell corrosion, the anode and cathode are on separate bars electrically connected through steel chairs or adjacent transverse bars, as illustrated in Figure 1.2 (Hansson, Pourasee, & Laurent, 2006). The use of sealers can protect the reinforcement from corrosion by preventing the intrusion of water and chlorides.

1.3 Objective and Scope

The objective of this research program was to investigate the long-term performance of concrete selected crack and deck sealers in regards to their effectiveness in reducing corrosion of bridge deck reinforcement when exposed to deicing salts with a goal of extending the service live of the bridge deck. The experimental program was developed and initiated by Lyrenmann (2011). The scope of his research included the following components:

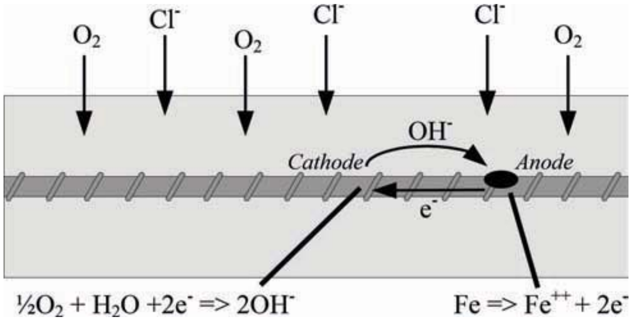


Figure 1.1 Microcell corrosion (Lyrenmann, 2011).

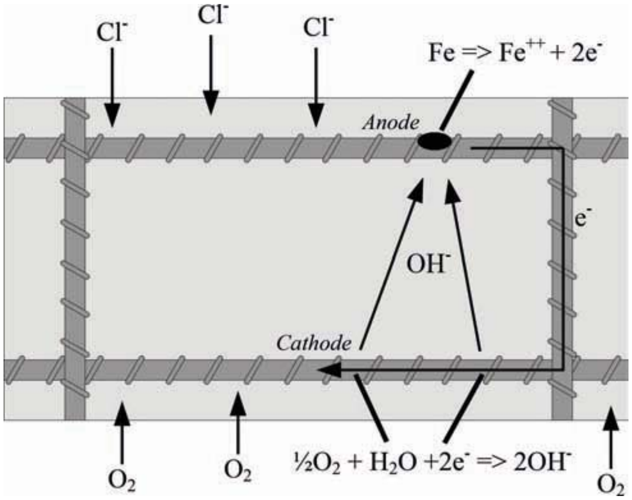


Figure 1.2 Macrocell corrosion (Lyrenmann, 2011).

- Compile a literature review regarding the relative performance of various sealers and installation methods.
- Survey State Departments of Transportation (DOTs) to determine the scope and success of current bridge deck preservation programs.
- Develop the experimental program and select test variables based on the results of the literature review and DOT survey.
- Construct the specimens and initiate the experimental program.

The scope of the research conducted here was as follows:

- Expose and monitor the test specimens for a total duration of 1600 days.
- Autopsy the specimens to evaluate crack and deck sealer performance.
- Evaluate the effectiveness of deck sealers in reducing corrosion when applied to unsealed decks exhibiting corrosion.
- Develop field application methods.
- Develop recommendations on the product selection and application.

Chapter 2 discusses the development and implementation of the experimental program. Chapter 3 presents approaches used to evaluate the performance of the sealers including monitoring of electrical current, autopsy of the specimens, rating methods, chloride penetration, and deck sealer penetration. Chapter 4 presents the test results along with a comparison of sealer performance. Chapter 5 discusses methods that can be used for the field implementation of a crack and deck sealing program. Finally, Chapter 6 presents conclusions from the experimental program and recommendations for implementation of a deck and crack sealer program.

2. EXPERIMENTAL PROGRAM

2.1 Introduction

The experimental program was developed by Lyrenmann (2011) to investigate the long-term effectiveness of sealers in reducing corrosion of deck reinforcement. Lyrenmann compiled a literature review to gather information regarding the relative performance of various sealers and installation methods. In addition, a survey of State Departments of Transportation (DOTs) investigated the scope and success of bridge deck preservation programs. The knowledge gained from the literature review and DOT survey guided the development of this experimental program and the selection of variables to be studied. A summary of the testing program is provided in this chapter, while more detailed information can be found in Lyrenmann (2011).

In addition to the variables of the original test program, it was desired to investigate the effectiveness of applying deck sealer to a previously unsealed bridge deck with pre-existing corrosion. To simulate this scenario, three unsealed control specimens were later sealed with a deck sealer. The specimens were evaluated for the deck sealers' effect on slowing the rate of corrosion.

2.2 Macrocell Specimen Design

A set of 90 reinforced concrete specimens, called macrocells, were cast on September 19, 2010, using an Indiana Department of Transportation (INDOT) Class C mix. Each macrocell specimen has a depth of 8 in., similar to that of a typical bridge deck. The specimens have a width of 8 in. and a length of 24 inches (Figure 2.1).

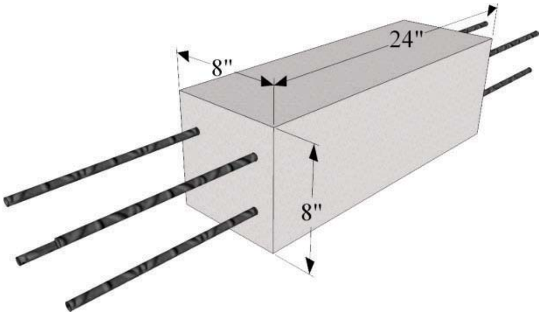


Figure 2.1 Macrocell dimensions (Lyrenmann, 2011).

The top and bottom mats of reinforcement are identical, each having two No. 4 longitudinal bars protruding from the concrete and three No. 4 transverse bars of 6 in. length. Bar locations are shown in Figure 2.2.

2.3 Specimen Cracking

Bridge decks are known to develop full-depth transverse cracks with a typical width in the range of 0.016 to 0.020 in. at a spacing of 8 to 10 ft along the span due to restrained concrete shrinkage (Frosch, Blackman, & Radabaugh, 2003). To replicate these cracks in the macrocell specimens, the loading setup shown in Figure 2.3 was used to grip the longitudinal bars to induce full-depth transverse cracks with a target width of 0.020 in.

Approximately two-thirds of the macrocell specimens were cracked in tension to simulate cracks in a bridge deck where salt water can flow directly onto the steel reinforcement. The applied tensile force produced three to four cracks in each specimen. Typically, three cracks formed at the locations of the transverse bars. Meanwhile, the remaining one-third of the specimens were not cracked, replicating the deck area spanning between cracks. In these regions, the uncracked but inherently porous concrete allows gradual infiltration of salt water, enabling corrosion of the reinforcing bars over time.

2.4 Specimen Groups

The 90 macrocells were sorted so each variable combination could be applied to a group of three specimens. Cracked specimen groups were organized by distributing the specimens with four cracks among the groups and by making the group average crack widths as uniform as possible. The cracked specimens constitute Groups 1 to 19. Groups comprised of uncracked specimens are designated with a "U" as Groups 20U to 30U. The specimen groups and crack widths are presented in Figure 2.4.

2.5 Application of Sealers

After cracking the specimens, crack and deck sealers were applied. The products used in this study include three crack sealers and three deck sealers as listed in

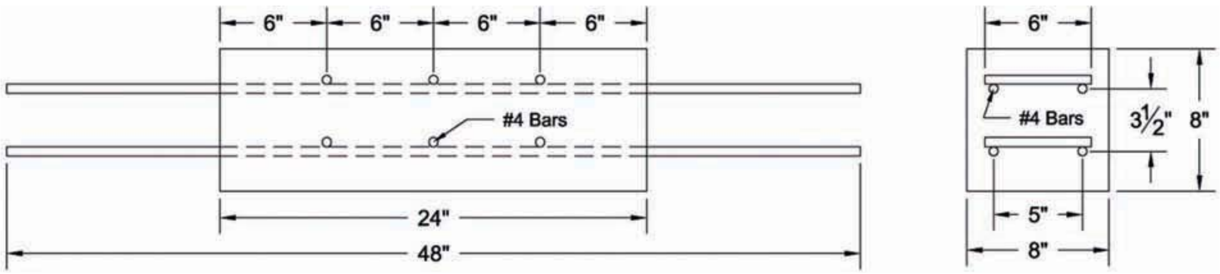


Figure 2.2 Specimen dimensions and reinforcement locations (Lyrenmann, 2011).

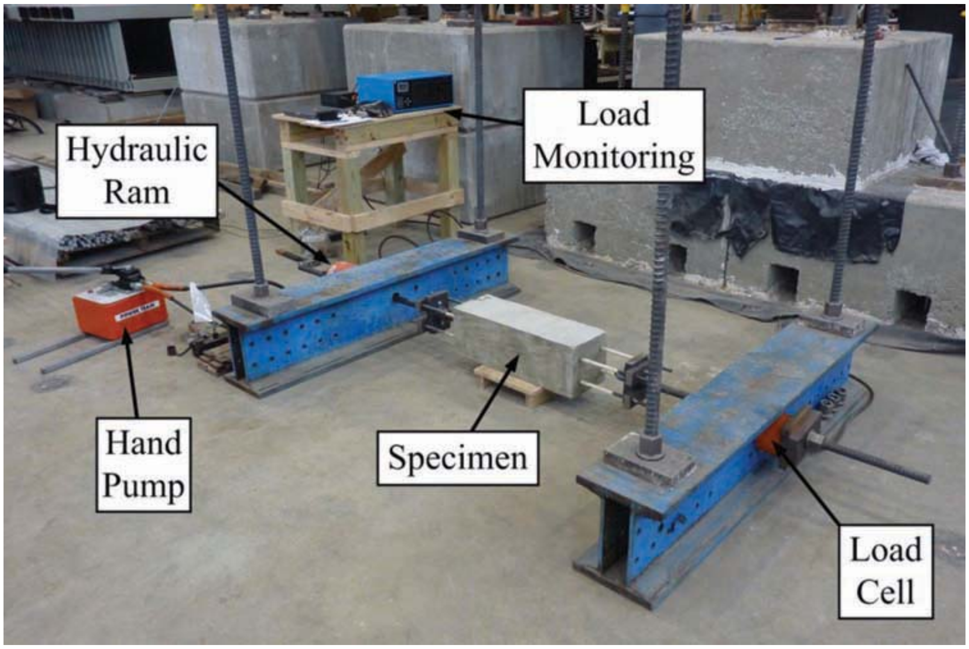


Figure 2.3 Specimen cracking system (Lyrenmann, 2011).

Table 2.1. These sealers have been documented as being effective at reducing corrosion, as revealed through a literature review and a survey of various State Departments of Transportation. The proprietary names of some of the products have been changed by their manufacturers since this study began. Former names are listed for reference in Table 2.1; however, the sealers will be referenced in this study by their current product names. It is also important to note that MasterProtect H 440 HZ, formerly Hydrozo Silane 40 VOC, is no longer permitted for use in the state of Indiana due to a change in volatile organic compound (VOC) emissions limitations, as dictated by the Indiana Administrative Code, Article 326 IAC 8-14 (Appendix A). This rule requires that waterproofing concrete or masonry sealers have a VOC limit of 400 grams/liter (g/L). MasterProtect H 440 HZ only reports the VOC content to be $<$ 600 g/L. Because it does not indicate a specific value, it is not possible for Indiana to determine compliance with the rule. Consequently, the product is considered to be in violation of the rule.

2.6 Application of Service-Load Stress

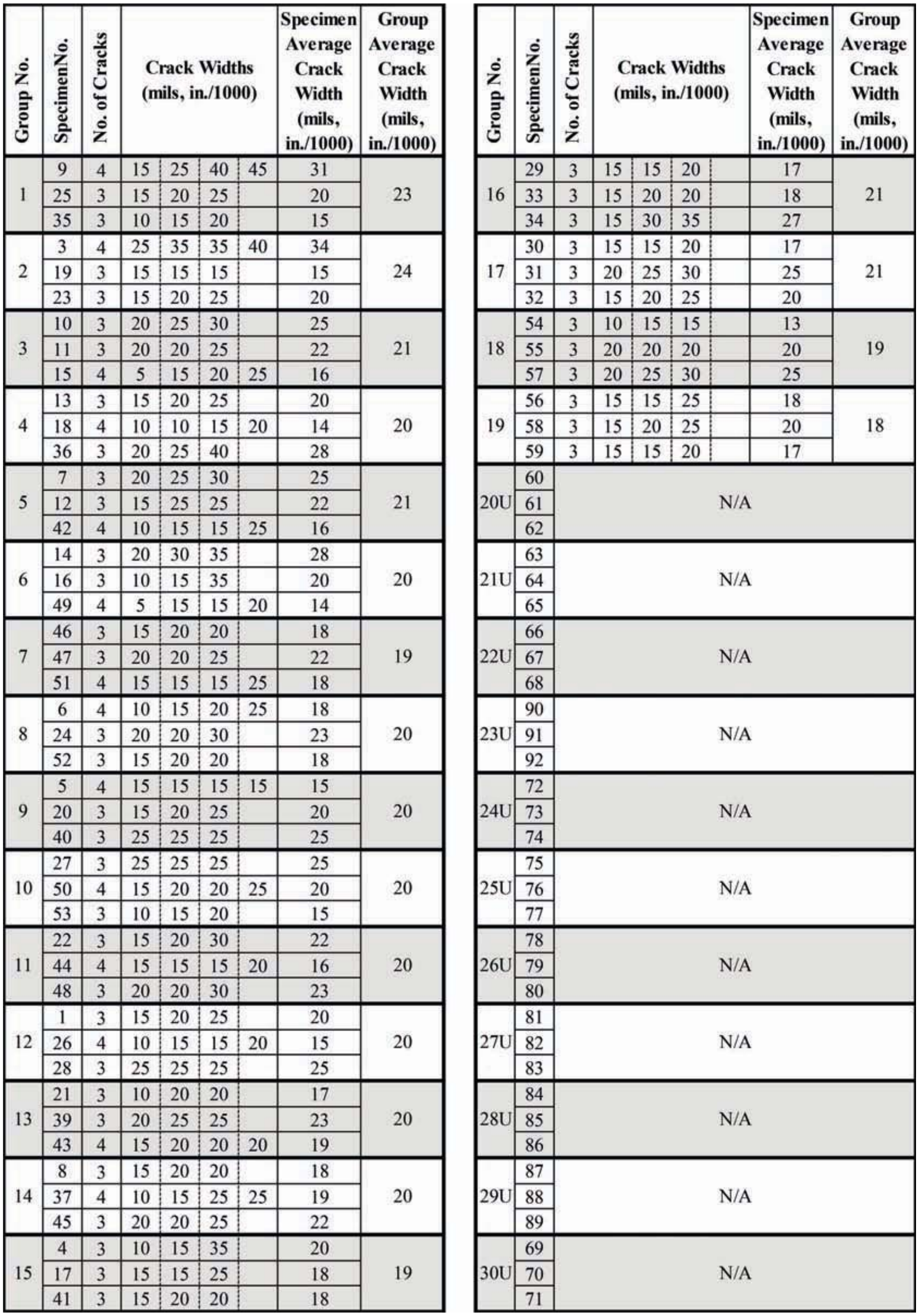
After the applied sealers were fully cured, the cracked specimens were then restressed to 2/3 of yield stress (40 ksi) to replicate additional stresses created in a bridge deck due to live traffic loading and thermal response, using the same cracking mechanism as shown in Figure 2.3. This operation was intended to provide a more accurate representation of crack sealer performance on a bridge deck as the sealers are subjected to stress. Sealers with adequate strength and flexibility should maintain their ability to resist salt water ingress despite restressing.

2.7 Salt Water Exposure

The specimens were exposed to chlorides by ponding salt water on the top surface to allow the solution to access the reinforcement through the cracks or through the pores of the concrete. To prevent the salt water from draining through the cracked specimens, the cracks were sealed on the sides and bottom of the specimens with silicone. Then, acrylic enclosures were constructed on the top of each specimen to facilitate ponding a depth of about 1.5 in. of salt water on the specimens using a saline solution that was 3%-by-weight sodium chloride.

The intent of the experiment was to study corrosion of the bars within the concrete due to chloride ingress only from salt water ponded on the top surface. To achieve this, precautions were taken to resist corrosion of the exposed steel and to prevent chloride ingress through the concrete on the other sides of the specimens. First, the ends of the longitudinal bars protruding from the concrete were painted with Rust-Oleum Stops Rust paint to resist corrosion. Finally, in accordance with ASTM G109-07 (2007), the exterior of the macrocell specimen was coated with a waterproofing product, Sikagard 62. The only areas of exposed concrete were the top surface to allow salt water ingress and some areas on the bottom surface to allow moisture to migrate out of the specimen. Figure 2.5 shows a specimen after application of these coatings.

The exposure regimen consisted of four-week cycles that each included both a wet and dry period. Salt water was poured into the acrylic enclosures and kept at a depth of 1.5 in. for two weeks. Then, the water was removed with a vacuum to allow the specimens to dry for two weeks. The first wet cycle was initiated on September 21, 2011, and the exposure regimen was continued throughout the experimental program.



Group No.	SpecimenNo.	No. of Cracks	Crack Widths (mils, in./1000)				Specimen Average Crack Width (mils, in./1000)	Group Average Crack Width (mils, in./1000)
1	9	4	15	25	40	45	31	23
	25	3	15	20	25		20	
	35	3	10	15	20		15	
2	3	4	25	35	35	40	34	24
	19	3	15	15	15		15	
	23	3	15	20	25		20	
3	10	3	20	25	30		25	21
	11	3	20	20	25		22	
	15	4	5	15	20	25	16	
4	13	3	15	20	25		20	20
	18	4	10	10	15	20	14	
	36	3	20	25	40		28	
5	7	3	20	25	30		25	21
	12	3	15	25	25		22	
	42	4	10	15	15	25	16	
6	14	3	20	30	35		28	20
	16	3	10	15	35		20	
	49	4	5	15	15	20	14	
7	46	3	15	20	20		18	19
	47	3	20	20	25		22	
	51	4	15	15	15	25	18	
8	6	4	10	15	20	25	18	20
	24	3	20	20	30		23	
	52	3	15	20	20		18	
9	5	4	15	15	15	15	15	20
	20	3	15	20	25		20	
	40	3	25	25	25		25	
10	27	3	25	25	25		25	20
	50	4	15	20	20	25	20	
	53	3	10	15	20		15	
11	22	3	15	20	30		22	20
	44	4	15	15	15	20	16	
	48	3	20	20	30		23	
12	1	3	15	20	25		20	20
	26	4	10	15	15	20	15	
	28	3	25	25	25		25	
13	21	3	10	20	20		17	20
	39	3	20	25	25		23	
	43	4	15	20	20	20	19	
14	8	3	15	20	20		18	20
	37	4	10	15	25	25	19	
	45	3	20	20	25		22	
15	4	3	10	15	35		20	19
	17	3	15	15	25		18	
	41	3	15	20	20		18	

Group No.	SpecimenNo.	No. of Cracks	Crack Widths (mils, in./1000)				Specimen Average Crack Width (mils, in./1000)	Group Average Crack Width (mils, in./1000)
16	29	3	15	15	20		17	21
	33	3	15	20	20		18	
	34	3	15	30	35		27	
17	30	3	15	15	20		17	21
	31	3	20	25	30		25	
	32	3	15	20	25		20	
18	54	3	10	15	15		13	19
	55	3	20	20	20		20	
	57	3	20	25	30		25	
19	56	3	15	15	25		18	18
	58	3	15	20	25		20	
	59	3	15	15	20		17	
20U	60	N/A						
	61							
	62							
21U	63	N/A						
	64							
	65							
22U	66	N/A						
	67							
	68							
23U	90	N/A						
	91							
	92							
24U	72	N/A						
	73							
	74							
25U	75	N/A						
	76							
	77							
26U	78	N/A						
	79							
	80							
27U	81	N/A						
	82							
	83							
28U	84	N/A						
	85							
	86							
29U	87	N/A						
	88							
	89							
30U	69	N/A						
	70							
	71							

Figure 2.4 Specimen groups (Lyrenmann, 2011).

TABLE 2.1
Sealer products.

Use	Product Name	Former Name	Manufacturer	Description
Crack Sealer	Sikadur 55 SLV	–	Sika Corp.	Low-viscosity epoxy
	Dural 335	–	Euclid Chemical	Low-viscosity epoxy
	MasterSeal 630	Degadeck CSP (Crack Sealer Plus)	BASF	Methacrylate
Deck Sealer	MasterProtect H 440 HZ	Hydrozo Silane 40 VOC	BASF	Solvent-based 40% silane penetrating sealer
	MasterProtect H 400	Enviroseal 40	BASF	Water-based 40% silane penetrating sealer
	Linseed Oil	–	Euclid Chemical	Blend of boiled linseed oil and solvents

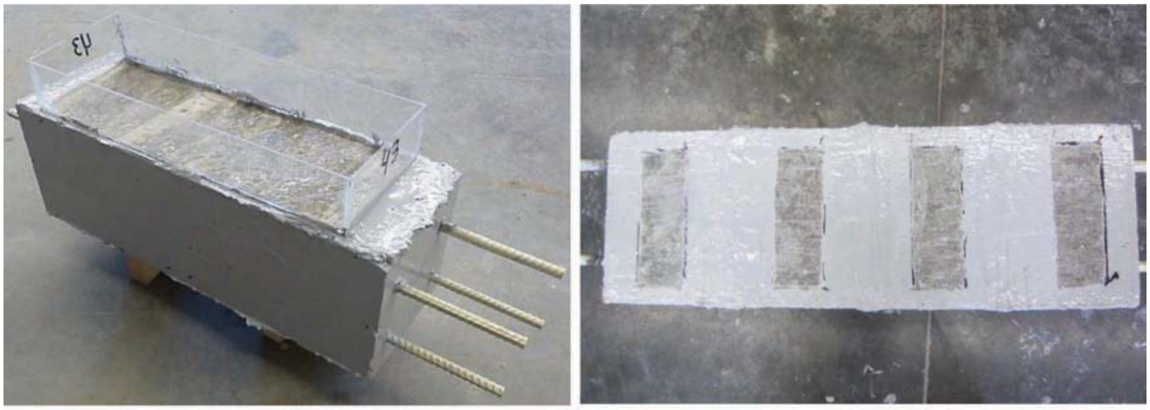

(a) Top surface and sides of specimen (b) Bottom surface of specimen

Figure 2.5 Waterproofed specimen (Lyrenmann, 2011).

2.8 Specimen Instrumentation

The ends of the longitudinal bars protruding from the concrete were instrumented to facilitate the measurement of electrical activity in each specimen. The two ends of a 14-gauge copper wire were wrapped around the two top bars and secured with electrical tape and plastic ties, electrically connecting the bars of the top mat of reinforcement. The same procedure was completed for the bottom mat. A 100-ohm resistor was soldered to connect the bottom mat to the top mat. The datalogger wires were soldered to either end of the resistor to allow the datalogger to record the voltage drop across the resistor. The completed electrical wiring is shown in Figure 2.6. Once the wiring was completed for the entire testing room (Figure 2.7), data acquisition was initiated on September 21, 2011, which coincided with the first day of salt water exposure.

2.9 Test Variables

The 90 macrocell specimens were divided into 30 groups of three, which allowed for a variety of variable combinations to be evaluated. Groups 1 to 19 were comprised of cracked specimens used to investigate corrosion activity resulting from crack sealers and deck sealers independently, crack and deck sealer combinations, no sealers, application of restressing after sealing, surface preparation for crack sealers, epoxy-coated reinforcement, and surface tining. The uncracked specimens of Groups 20U to 30U were studied for the effects of deck sealers, surface preparation for deck sealers, and traffic wear on deck sealers.

Figure 2.8 lists the groups, specimens, and variables that constitute the test matrix. As mentioned previously, groups with numbers followed by a “U” are uncracked specimens (Groups 20U to 30U). Unsealed control specimens in Groups 11, 23U, and 30U were later sealed with MasterProtect H 400 at 1375 days (shown with specimen number followed by “-S”), as discussed in Section 2.10. One specimen in each group, denoted by an asterisk (*), was autopsied and removed from the test during a preliminary autopsy by Pollastrini in 2013. These specimens were selected based upon a review of recorded electrical data, and the reason for selection is noted in Table 2.2. The selected specimens were disconnected from the datalogger after Day 617. As a result, test data up to 1600 days was only collected from the two remaining specimens from each group. The specimens opened during the preliminary autopsy in 2013 denoted by an asterisk (*) only have electrical data recorded up to 617 days.

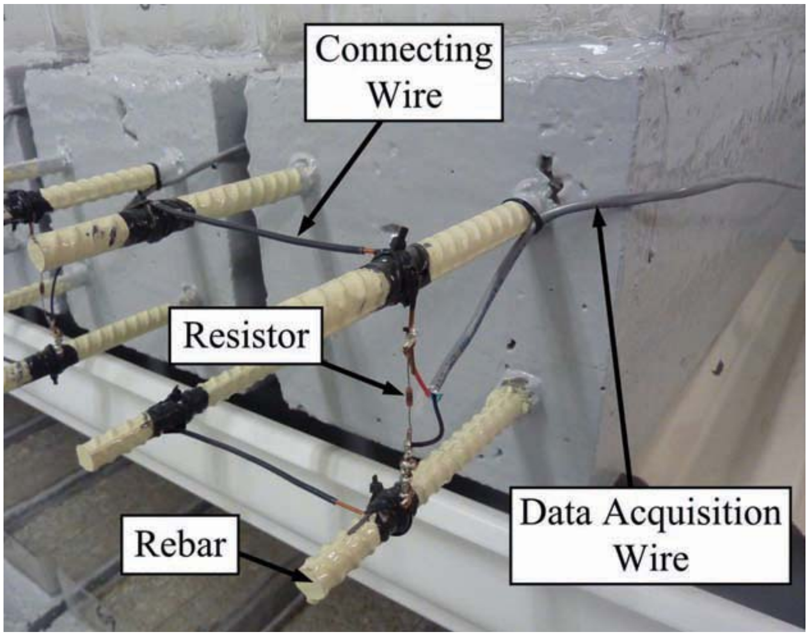


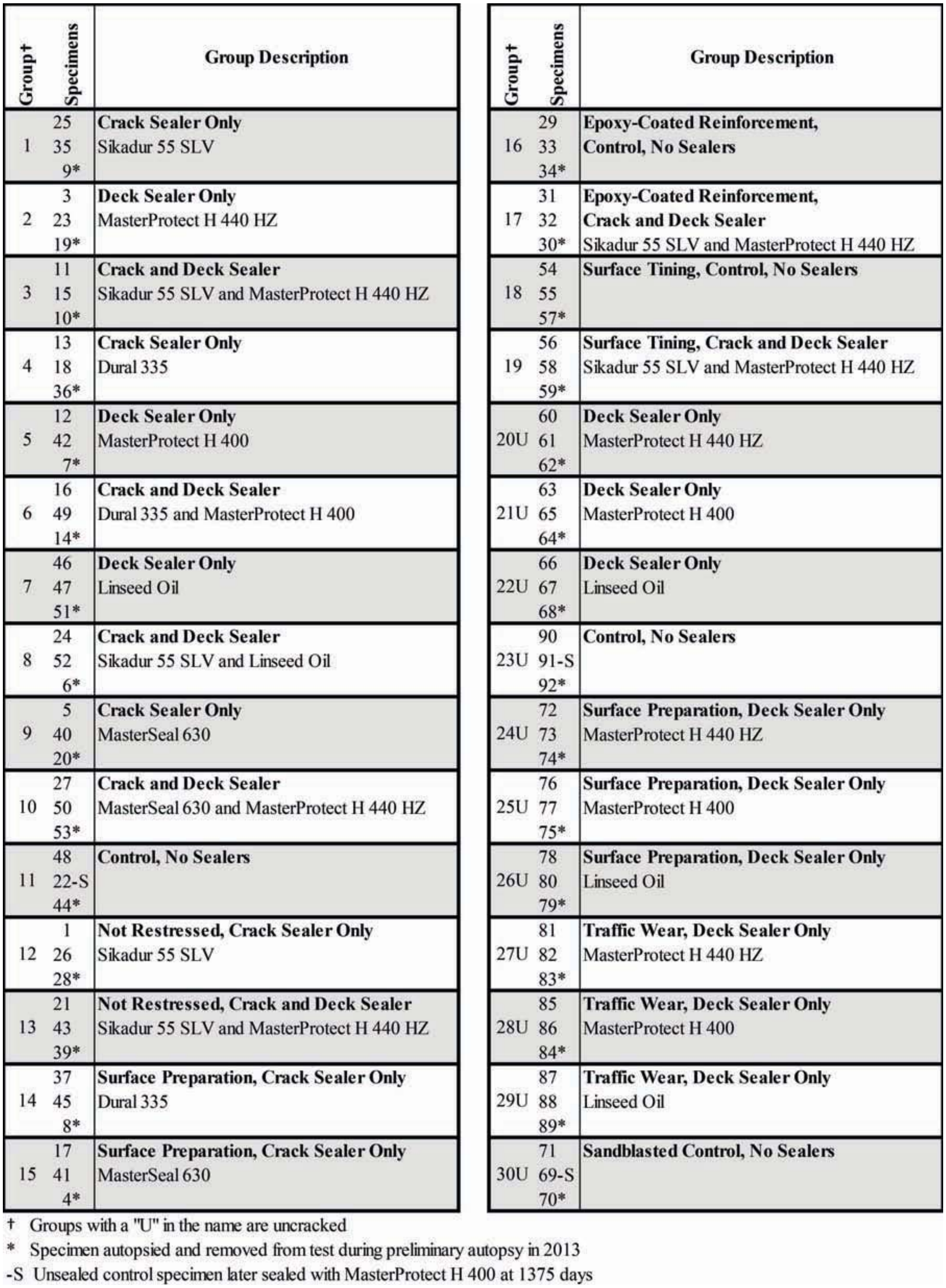
Figure 2.6 Specimen instrumentation (Lyrenmann, 2011).

Figure 2.7 All specimens prepared for data acquisition (Lyrenmann, 2011).

2.9.1 Crack Sealers

The crack sealers Sikadur 55 SLV, Dural 335, and MasterSeal 630 were applied to cracked Groups 1, 4, and 7, respectively. As shown in Table 2.1, Sikadur 55 SLV and Dural 335 are both low-viscosity epoxies, while MasterSeal 630 is a methacrylate. During installation, the most distinguishing difference between the epoxy and methacrylate sealers was their viscosities. The low-viscosity epoxies have a viscosity of 80 to 105 centipoise (cP); however, the methacrylate has a much thinner consistency with a viscosity of only 5-15 cP, similar to that of water.

Performance of epoxy and methacrylate sealers was studied by Frosch, Gutierrez, and Hoffman in 2010. Epoxy crack sealers were recommended for larger crack widths (> 0.016 in.), while methacrylate crack sealers were recommended for smaller crack widths (< 0.016 in.) (Frosch et al., 2010). The crack widths in this study are at the transition point; therefore, both products were evaluated.



Group†	Specimens	Group Description
1	25 35 9*	**Crack Sealer Only** Sikadur 55 SLV
2	3 23 19*	**Deck Sealer Only** MasterProtect H 440 HZ
3	11 15 10*	**Crack and Deck Sealer** Sikadur 55 SLV and MasterProtect H 440 HZ
4	13 18 36*	**Crack Sealer Only** Dural 335
5	12 42 7*	**Deck Sealer Only** MasterProtect H 400
6	16 49 14*	**Crack and Deck Sealer** Dural 335 and MasterProtect H 400
7	46 47 51*	**Deck Sealer Only** Linseed Oil
8	24 52 6*	**Crack and Deck Sealer** Sikadur 55 SLV and Linseed Oil
9	5 40 20*	**Crack Sealer Only** MasterSeal 630
10	27 50 53*	**Crack and Deck Sealer** MasterSeal 630 and MasterProtect H 440 HZ
11	48 22-S 44*	**Control, No Sealers**
12	1 26 28*	**Not Restressed, Crack Sealer Only** Sikadur 55 SLV
13	21 43 39*	**Not Restressed, Crack and Deck Sealer** Sikadur 55 SLV and MasterProtect H 440 HZ
14	37 45 8*	**Surface Preparation, Crack Sealer Only** Dural 335
15	17 41 4*	**Surface Preparation, Crack Sealer Only** MasterSeal 630
16	29 33 34*	**Epoxy-Coated Reinforcement, Control, No Sealers**
17	31 32 30*	**Epoxy-Coated Reinforcement, Crack and Deck Sealer** Sikadur 55 SLV and MasterProtect H 440 HZ
18	54 55 57*	**Surface Tining, Control, No Sealers**
19	56 58 59*	**Surface Tining, Crack and Deck Sealer** Sikadur 55 SLV and MasterProtect H 440 HZ
20U	60 61 62*	**Deck Sealer Only** MasterProtect H 440 HZ
21U	63 65 64*	**Deck Sealer Only** MasterProtect H 400
22U	66 67 68*	**Deck Sealer Only** Linseed Oil
23U	90 91-S 92*	**Control, No Sealers**
24U	72 73 74*	**Surface Preparation, Deck Sealer Only** MasterProtect H 440 HZ
25U	76 77 75*	**Surface Preparation, Deck Sealer Only** MasterProtect H 400
26U	78 80 79*	**Surface Preparation, Deck Sealer Only** Linseed Oil
27U	81 82 83*	**Traffic Wear, Deck Sealer Only** MasterProtect H 440 HZ
28U	85 86 84*	**Traffic Wear, Deck Sealer Only** MasterProtect H 400
29U	87 88 89*	**Traffic Wear, Deck Sealer Only** Linseed Oil
30U	71 69-S 70*	**Sandblasted Control, No Sealers**

† Groups with a "U" in the name are uncracked

* Specimen autopsied and removed from test during preliminary autopsy in 2013

-S Unsealed control specimen later sealed with MasterProtect H 400 at 1375 days

Figure 2.8 Assigned test variables.

Prior to product application, the cracks were cleaned with compressed air to remove dust and debris. The cracks were sealed at the side and bottom surfaces of the specimens with masking tape to prevent the products from draining during installation. At this stage, silicone had not yet been applied at the cracks on the sides and bottom surface of the concrete. The silicone was applied later to prevent the salt water from

TABLE 2.2
Preliminary autopsy specimen selection notes.

Group	Specimen Autopsied	Selection Notes
1	9	Specimen shows electrical activity during beginning of experiment
2	19	Specimen exhibits middle electrical activity during past 150 days
3	10	Specimen has 3 cracks, similar to most other specimens being selected
4	36	Specimen exhibits slightly more electrical activity
5	7	Specimen exhibits middle electrical activity
6	14	Specimen shows initial electrical activity followed by an unusual trend of decreasing electrical activity
7	51	Specimen exhibits middle electrical activity during past 100 days
8	6	Specimen shows a large, positive current spike
9	20	Specimen displays largest electrical activity
10	53	Specimen exhibits middle electrical activity
11	44	Specimen exhibits middle electrical activity
12	28	Specimen exhibits largest electrical activity
13	39	Specimen shows slightly positive current, and has the most measurement "noise"
14	8	Specimen shows unusual current spike
15	4	Specimen exhibits slightly more electrical activity
16	34	Specimen exhibits slightly more electrical activity
17	30	Corrosion appears on the small areas of the concrete surface
18	57	Specimen exhibits middle electrical activity for majority of experiment
19	59	Specimen displays the least amount of measurement "noise"
20U	62	All samples appear similar; no distinguishing attributes
21U	64	All samples appear similar; no distinguishing attributes
22U	68	All samples appear similar; no distinguishing attributes
23U	92	Specimen displays the earliest onset of electrical activity
24U	74	All samples appear similar; no distinguishing attributes
25U	75	All samples appear similar; no distinguishing attributes
26U	79	Specimen displays a small current spike early in experiment
27U	83	All samples appear similar; no distinguishing attributes
28U	84	Specimen with large current spike is desired to be left in commission
29U	89	All samples appear similar; no distinguishing attributes
30U	70	Specimen exhibits middle electrical activity

draining through the cracks. Crack sealers were applied by a gravity feed method of pouring the product over the cracks, as shown in Figure 2.9. A squeegee was used to pond the material at the cracks so more sealer could be added until product refusal.

2.9.2 Deck Sealers

The deck sealers MasterProtect H 440 HZ, MasterProtect H 400, and Linseed Oil were applied to the surfaces of cracked Groups 2, 5, and 7. Compressed air was used to clean the cracks and surface of dust and debris prior to product application. The volume of material selected for each product application was determined to be within the target coverage range specified by the product manufacturer. The sealers were applied by brush with the recommended number of coats and the recommended duration of drying time between coats. No intentional filling of the cracks was performed as these materials were considered for use as a surface sealer. Application of deck sealers is shown in Figure 2.10.

2.9.3 Crack Sealer and Deck Sealer Combinations

The four combinations of crack and deck sealers listed in Table 2.3 were applied to cracked specimens in Groups 3, 6, 8, and 10. For each specimen, the crack sealer was applied first and allowed to cure, followed by the application of the deck sealer. Crack sealer and deck sealer installations were completed as discussed previously in Sections 2.9.1 and 2.9.2.

2.9.4 Control

Group 11 serves as the cracked control group with no applied sealers. The salt water ponded on these specimens was able to flow through the full-depth cracks to initiate the corrosion process as early as the first test day.

2.9.5 Restressing

As discussed previously, the cracked specimens were restressed to 2/3 of yield stress (40 ksi) following the curing of the sealers to simulate stresses in a bridge deck in the field due to concrete shrinkage, thermal effects, and loading conditions. However, it was desired to compare the effects of sealers in restressed specimens with the effects of identical sealers in specimens that had not been restressed. Group 12 was used to study the effectiveness of Sikadur 55 SLV when the specimen has not been restressed. The specimens of Group 13 were also not restressed after being treated with the sealer combination of Sikadur 55 SLV and MasterProtect H 440 HZ.

2.9.6 Surface Preparation for Crack Sealers

The manufacturers of two of the three crack sealers, Dural 335 and MasterSeal 630, recommend light sandblasting or shotblasting of the entire concrete surface area followed by cleaning with compressed air prior to sealer installation. To study this recommendation, the entire top surface of the specimens in Groups 14 and 15 were lightly sandblasted prior to the application of Dural 335 and MasterSeal 630, respectively. A visual comparison of the typical smooth specimen surface finished with a magnesium float and the surface after light sandblasting is presented in Figure 2.11.

Figure 2.9 Installation of crack sealers (Lyrenmann, 2011).

2.9.7 Epoxy-Coated Reinforcement

Although standard black steel reinforcement was used to construct the specimens in this study, epoxy-coated reinforcement is typically used for construction of bridge decks in the state of Indiana. Consequently, it was desired to include epoxy-coated reinforcement in two specimen groups. Group 16 consisted of cracked control specimens incorporating epoxy-coated bars and no applied sealers. Epoxy-coated reinforcement was also used in Group 17, which was subsequently treated with a sealer combination of Sikadur 55 SLV and MasterProtect H 440 HZ.

The epoxy coating of the reinforcement is prone to damage in the field during transport, erection, and casting. Such defects in the coating become localized areas of vulnerability that allow chlorides to access the steel and initiate corrosion. To simulate these flaws in the epoxy coating, a grinder was used to expose a targeted amount of 2 percent of the total surface area of

TABLE 2.3
Sealer combinations.

Group No.	Crack Sealer	Deck Sealer
3	Sikadur 55 SLV (Epoxy)	MasterProtect H 440 HZ** (Solvent-based 40% silane)
6	Dural 335 (Epoxy)	MasterProtect H 400 (Water-based 40% silane)
8	Sikadur 55 SLV (Epoxy)	Linseed Oil
10	MasterSeal 630 (Methacrylate)	MasterProtect H 440 HZ** (Solvent-based 40% silane)

**Use of MasterProtect H 440 HZ is no longer permitted in the state of Indiana.

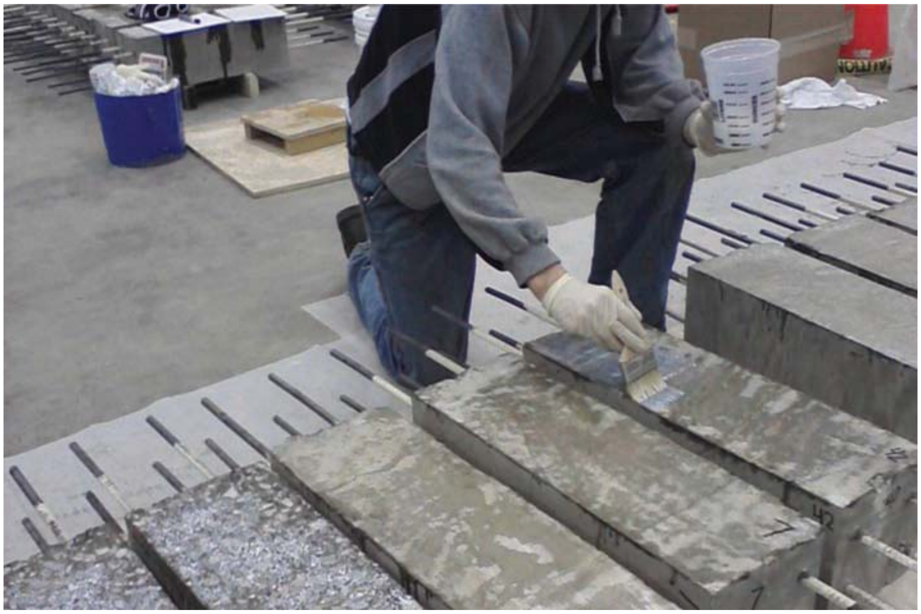


Figure 2.10 Application of deck sealers (Lyrenmann, 2011).

Figure 2.11 Sandblasting surface preparation for crack sealers (Lyrenmann, 2011).

the bar contained within the concrete specimen. This amount of damaged coating is the maximum amount allowed before it is required to be repaired in accordance with ASTM A775 (2016). Intentional damage was induced to small areas at 3 in. increments along the longitudinal reinforcing bars (Figure 2.12) and at 1.25 in. increments along the transverse bars. Damage at these locations allowed for direct contact of the black steel of the longitudinal and transverse bars, which created electrical connection between the bars.

2.9.8 Surface Tining

Bridge decks are typically constructed with surface tining to roughen the deck to create a safer driving surface for icy conditions. The tool shown in Figure 2.13 was constructed to form tines in the surface of the specimens in Groups 18 and 19, simulating bridge deck tining. Cracked control Group 18 was treated with surface tining and no sealers to understand the effect of a surface tined surface on salt water ingress over time. Group 19 was surface tined and treated with a combination of Sikadur 55 SLV and MasterProtect H 440 HZ to determine whether the roughened surface would impede the sealers' ability to penetrate and protect the cracks and the surface. Completed specimens with surface tining are shown in Figure 2.14.

2.9.9 Deck Sealers (Uncracked Specimens)

Groups 20U, 21U, and 22U consist of uncracked specimens treated with deck sealers MasterProtect H 440 HZ, MasterProtect H 400, and Linseed Oil, respectively. The surface of these specimens is a typical smooth finish created using a magnesium float. Deck sealers were applied in the same manner as discussed previously in Section 2.9.2. Group 23U serves as the uncracked control group.

2.9.10 Surface Preparation for Deck Sealers (Uncracked Specimens)

Deck sealer product manufacturers often specify sandblasting or shotblasting followed by cleaning with compressed air prior to sealer application. This procedure may open the pores of the concrete structure, allowing for deeper penetration of the sealer. Groups 24U, 25U, and 26U were sandblasted to a depth of 1/16 in. prior to the application of MasterProtect H 440 HZ, MasterProtect H 400, and Linseed Oil, respectively. A comparison of the typical smooth, magnesium float surface and the sandblasted surface is shown in Figure 2.15. Group 30U serves as an uncracked control group with 1/16in. of sandblasting and no applied sealers.

2.9.11 Deck Sealer Traffic Wear (Uncracked Specimens)

Traffic wear on a sealed bridge deck slowly abrades the top surface of the concrete, where the penetrating sealer has filled a layer of the concrete pores to prevent the ingress of salt water. Over time, this protective layer is worn away, reducing the sealer's ability to protect the reinforcement from corrosion. To study the effects of

Figure 2.12 Damage introduced in epoxy coating (Lyrenmann, 2011).

Figure 2.13 Surface tining tool (Lyrenmann, 2011).

Figure 2.14 Specimens with surface tining (Lyrenmann, 2011).

traffic wear on deck sealers, specimens with a smooth, magnesium float finish were sealed with a deck sealer, allowed to cure, and then sandblasted. A depth of 1/16 in. of sandblasting (Figure 2.15) was used to simulate 10 years of traffic wear on a sealed bridge deck. Groups 27U, 28U, and 29U were treated with MasterProtect H 440 HZ, MasterProtect H 400, and Linseed Oil, respectively, followed by sandblasting. Group 30U served as an uncracked control group with 1/16 in. of sandblasting and no applied sealers.

2.10 Application of Deck Sealer to Previously Unsealed Control Specimens

To simulate the application of a deck sealer to an existing bridge deck with actively-corroding reinforcement, deck sealers were applied on test day 1375 to three control specimens, each from a different control group. At this stage of the experiment, only two specimens remained in each group because one specimen of each group was autopsied at 617 days. Of the two specimens remaining in each control group, the one recording the highest electrical activity was selected to be sealed at 1375 days.

The specimens selected for sealing included cracked control No. 22 from Group 11, uncracked control No. 91 from Group 23U, and sandblasted uncracked control No. 69 from Group 30U. Prior to being sealed, the specimen surfaces were first cleaned with compressed air. The specimens were then sealed with MasterProtect H 400 (water-based, 40-percent silane).

2.10.1 Application of Deck Sealer to Cracked Control Specimen

For the cracked control Specimen No. 22, the cracks were first flooded using a squeegee to pond the material over the cracks (Figure 2.16). A brush was then used to apply sealer to the entire top surface of the specimen. The specimen immediately after sealing is shown in Figure 2.17.


(a) Before sandblasting (b) 1/16 in. sandblasting

Figure 2.15 Sandblasting surface preparation for deck sealers (Lyrenmann, 2011).

Figure 2.16 Applying deck sealer to cracked control Specimen No. 22.

Figure 2.17 Sealer applied to cracked control Specimen No. 22.

2.10.2 Application of Deck Sealer to Uncracked Control Specimens

Prior to sealing uncracked Specimens No. 91 and No. 69, it was noted that cracks had formed in the top surface of both specimens. Although these specimens were originally uncracked, it is presumed that the cracking was caused by expansion of the corroded reinforcement within the specimens. The crack patterns observed prior to sealing are outlined in Figure 2.18. During sealer application, there was no attempt made to flood the cracks. Instead, a volume of sealer measured to be within the recommended coverage range was brushed onto the top surface of the specimens (Figure 2.19). Photos of the specimens directly after sealer application are shown in Figure 2.20.

(a) Specimen No. 91

(b) Specimen No. 69

Figure 2.18 Crack patterns observed on uncracked control specimens.

Figure 2.19 Applying deck sealer to uncracked control Specimen No. 91.

(a) Specimen No. 91

(b) Specimen No. 69

Figure 2.20 Sealer applied to uncracked control specimens.

3. PERFORMANCE ASSESSMENT

3.1 Introduction

The effectiveness of sealers in reducing corrosion was examined throughout the duration of the study and at the completion of the experimental program using several different approaches. Corrosion was monitored throughout the 1600 test days by measuring macrocell electrical activity. After 617 days, a preliminary autopsy of one-third of the specimens was completed by Pollastrini (2013) to visually assess corrosion progress and correlate the electrical data with the observed corrosion. Following the completion of 1600 days, the remaining two-thirds of the specimens were autopsied, and two rating schemes were used to quantify the amount of corrosion observed in the specimens. Finally, studies of chloride penetration depth and sealer penetration depth were used to further investigate the effectiveness of deck sealers in uncracked concrete. The subsequent sections discuss the equipment and procedures implemented to collect and process the data recorded through each of the approaches.

3.2 Electrical Measurements

Using physical observation to monitor corrosion throughout the duration of the experiment is not practical, as it would require periodic autopsies, thus destroying the specimens. However, measurement of the electrical current allows for nondestructive monitoring of the corrosion activity throughout the experimental program.

Corrosion is an electrical process involving the flow of electrons from anodic to cathodic locations in the steel reinforcement. Macrocell corrosion involves the formation of the anode and cathode locations on separate mats of reinforcement; therefore, the electrons flow from the top mat to the bottom mat, or vice versa. By attaching a resistor to the bars to connect the top mat to the bottom mat and using a datalogger to periodically record the difference in voltage on either side of the resistor, it is possible to measure the current, or flow of electrons, between the two mats, thus measuring corrosion occurring in the specimen.

3.2.1 Data Collection

A Campbell Scientific CR10X datalogger was used to automatically record measurements of the voltage drop across the resistor every six hours. The resulting output consisted of four voltage measurements per day over a period of 1600 days.

3.2.2 Sources of Data Error

Two identified sources of electrical data error include data discontinuities and corrosion of exposed steel.

TABLE 3.1
Erroneous electrical data points.

Group No.	Specimen No.	No. of Days in Service	No. of -6999 Data Points	Total No. of Data Points Recorded	Percentage of Total
2	3	1600	2013	6400	31.5%
8	6*	617	239	2468	9.5%
2	19*	617	195	2468	7.8%
6	49	1600	494	6400	7.7%
24U	73	1600	416	6400	6.5%
14	8*	617	121	2468	4.8%
24U	74*	617	8	2468	0.32%
11	44*	617	5	2468	0.20%
25U	75*	617	1	2468	0.04%

*Specimen autopsied and removed from test during preliminary autopsy in 2013.

Figure 3.1 Corrosion of exposed steel.

3.2.2.1 Data Discontinuities. There are two circumstances in which linear interpolation was used to fill gaps in the data collected over the 1600 test days. First, some of the raw data collected from the datalogger included data points with a value of "-6999" instead of the voltage drop measured in millivolts (mV). These values appeared in nine of the specimens, as listed in Table 3.1. Secondly, linear interpolation was used to fill a 22-day gap in the data collection from Day 1376 to Day 1397, due to temporary loss of power to the datalogger.

3.2.2.2 Corrosion of Exposed Steel. It is important to note that the electrical measurements recorded by the datalogger include all corrosion activity, including that potentially occurring on the exposed ends of the bars protruding from the concrete. This is critical because the intent of the macrocell specimen is to evaluate the sealers' effectiveness in reducing corrosion by preventing salt water ingress from the top surface of the specimen. Therefore, only corrosion occurring inside the concrete is relevant to the performance of the sealers.

The highly-corrosive environment of the testing room often led to corrosion at the protruding ends of the longitudinal bars (Figure 3.1), despite the fact that these locations were sealed with Rust-Oleum Stops Rust paint and waterproofing sealer Sikagard 62. Corrosion of the protruding ends of the bars increases the measured electrical current, which results in electrical data that overestimates the corrosion occurring within the specimen. Corrosion of the exposed steel is considered to be a source of error in this study because its occurrence is unrelated to the performance of the applied sealers.

In an attempt to mitigate this error, a drill with a wire brush attachment was used periodically throughout the test to remove any corrosion observed on the exposed steel. Following removal of the corrosion, the exposed steel was then resealed with the waterproofing sealer, Sikagard 62. However, it was found during autopsy that corrosion often continued to progress unseen beneath the waterproofing sealer. The severity of corrosion on the exposed steel was assessed as part of the visual rating system during autopsy to identify electrical measurements with possible contributions due to corrosion of exposed steel. Documentation of exposed steel corrosion is discussed further in Sections 3.3.4.1 and 3.3.4.2.

3.2.3 Data Processing

A Campbell Scientific CR10X datalogger produced a record of the electrical potential (voltage drop) across the resistor, measured in millivolts (mV), which included four data points per day for 1600 test days. The voltage data was first converted from millivolts to volts and then the average value of electrical potential was calculated for each day. Using the daily average electrical potential, the total corrosion was calculated using equations according to ASTM G109-07 (2007).

3.2.3.1 Ohm's Law. Ohm's Law defines the relationship between electrical potential, resistance, and current (Equation 3.1). The resistance of each 100-ohm resistor was measured to the nearest hundredth ohm using a multimeter. Current (I) was calculated using the known quantities of resistance (R) and electrical potential (V).

$$I = V/R \tag{3.1}$$

I = Current (amperes)
V = Electrical potential (volts)
R = Resistance (ohms)

3.2.3.2 Total Corrosion. The current was integrated over time to determine the total current (often referred to as total corrosion), in coulombs, using the equation presented in ASTM G109-07 (2007), Section 10.1.8 (Equation 3.2). The integration is computed by summing the trapezoidal areas under the current versus time curve between adjacent time steps.

$$TC_j = TC_{j-1} + \left[(t_j - t_{j-1}) \cdot \left(\frac{i_j + i_{j-1}}{2} \right) \right] \tag{3.2}$$

TC_j = Total corrosion (coulombs) at time-step j
t_j = Time (seconds) at time-step j
i_j = Current (amperes) at time-step j

3.3 Autopsy of Specimens

After the acquisition of 1600 days of electrical activity data, the specimens were autopsied from February 29 to April 9, 2016. An electric saw with a diamond-tipped blade was used to create longitudinal cuts in the specimens. A hammer, chisel, and pry bar were then used to expose and remove the longitudinal reinforcement. The transverse bars were not removed from the uncracked specimens. However, in the cracked specimens, the transverse bars were typically positioned at the cracks, which facilitated their removal. At the completion of each autopsy, the reinforcing bars were carefully examined, and the corrosion was visually evaluated. The severity of corrosion was quantified using two different rating methods, as described in Section 3.3.4. The condition of each specimen was documented with photographs throughout autopsy and evaluation which allows them to be referenced later during final data analysis.

Although all the other specimens in the experiment were autopsied after 1600 test days, the three control specimens that were sealed at 1375 days remained connected to the datalogger and exposed to salt water ponding until 1742 test days to prolong the investigation of the effects of the sealer application. The three sealed control specimens were then disconnected and autopsied at 1742 days.

3.3.1 Preparation of a Specimen for Autopsy

After first being disconnected from the datalogger, the specimens were removed from the testing room. The acrylic salt water ponding enclosures were removed, and the protruding ends of the longitudinal bars were labeled with the group number, specimen number, and bar location (top right, top left, bottom right, or bottom left). Two cut lines were drawn on each of the four longitudinal faces. The locations of the cracks were recorded for the cracked specimens (Appendix B provides complete details). Any distinguishing features were documented with photographs and notes. Figure 3.2 shows a specimen prepared for autopsy.

3.3.2 Cutting

Specimens were cut using a Hilti DCH-EX 300 electric saw and 12 in. diamond-tipped blade (Figure 3.3) with an attached Hilti VC 40-U vacuum used to contain the majority of the dust produced. Cuts were made along lines parallel to and at least 0.5 in. offset from the longitudinal bars to avoid inadvertent damage to the bars. Two cuts were made on each of the four longitudinal faces, totaling eight (8) cuts per specimen, as shown in Figure 3.4.

3.3.3 Specimen Autopsy

A hammer, chisel, and pry bar were used to expose the longitudinal reinforcement (Figure 3.5) while exercising caution to avoid damage to the bars. Photographs were taken prior to removing the bars, often with the detached pieces of concrete placed on the top surface of the specimen to show the steel-to-concrete interface as seen in Figure 3.6. The longitudinal bars were removed from the specimen after cutting the plastic ties that held them fastened to the transverse

Figure 3.2 Specimen prepared for autopsy.

Figure 3.3 Cutting the specimens.

bars. For cracked specimens, the transverse bars were then labeled prior to removal. The transverse bars were tapped with a hammer to split open the concrete at the cracks (Figure 3.7). Another tap from the hammer dislodged the transverse bars from the concrete at the crack interface. In the few cases when the cracks were not at the location of the transverse bars, additional saw cuts were made to induce cracks allowing

Figure 3.4 Specimen with completed cuts.

access to the transverse bars. Corrosion product observed staining the concrete at a crack interface was documented with photographs as shown in Figure 3.8.

3.3.4 Autopsy Ratings of Observed Corrosion

Once the reinforcing bars were removed from the concrete, they were closely examined for corrosion. Two rating methods were used to quantify the severity of corrosion observed. The first rating method was used by Pollastrini (2013) during the preliminary specimen autopsies in 2013 and was based on a method originally developed by Salas, Kotys, West, Breen, and Kreger (2002). This approach is referred to here as the Autopsy Increment Rating Method. Additionally, in an effort to make the visual ratings as objective as possible, corrosion was also quantified using a second method referred to here as the Autopsy Crack Location Rating Method. The notes and visual ratings recorded during autopsy for each specimen are presented in Appendix C.

3.3.4.1 Autopsy Increment Rating Method. Salas et al. (2002) developed a method of rating the severity of observed corrosion on mild steel bars. A modified version of this method was selected for use in this study because it incorporates both the extent and degree of corrosion. This section discusses the original method developed by Salas et al. (2002), the modifications to the method that were implemented in this study, and the modifications to the method that were used during the preliminary autopsy (Pollastrini, 2013).

Figure 3.5 Autopsying the specimens.

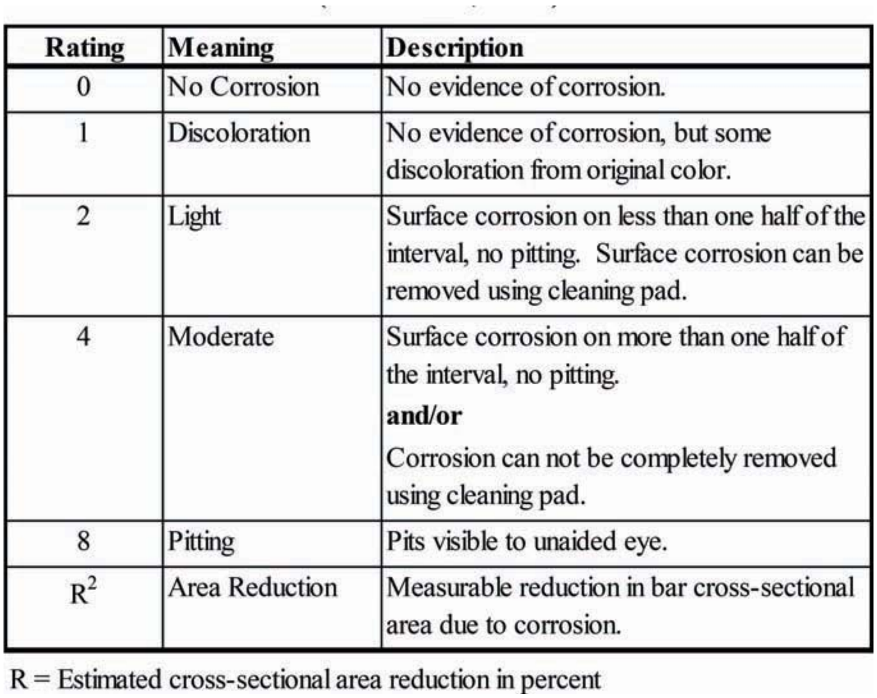
3.3.4.1.1 Autopsy Increment Rating Method Developed by Salas et al. (2002). The rating method developed by Salas et al. (2002) involves dividing the length of the bars into increments, examining each increment, and assigning a numerical rating based on

Figure 3.6 Steel-to-concrete interface at autopsy.

Figure 3.7 Specimen split at the cracks.

Figure 3.8 Corrosion product at crack interface.

the corrosion observed within its length. Ratings are assigned at intervals along both the top and bottom halves of each bar. The numerical rating scale and descriptions developed by Salas are presented in Figure 3.9. The total specimen corrosion rating is calculated by the summation of all the increment ratings for the top and bottom halves of all the bars in the specimen as shown by Equation 3.3.



Rating	Meaning	Description
0	No Corrosion	No evidence of corrosion.
1	Discoloration	No evidence of corrosion, but some discoloration from original color.
2	Light	Surface corrosion on less than one half of the interval, no pitting. Surface corrosion can be removed using cleaning pad.
4	Moderate	Surface corrosion on more than one half of the interval, no pitting. **and/or** Corrosion can not be completely removed using cleaning pad.
8	Pitting	Pits visible to unaided eye.
R^2	Area Reduction	Measurable reduction in bar cross-sectional area due to corrosion.

R = Estimated cross-sectional area reduction in percent

Figure 3.9 Evaluation and rating system for corrosion found on mild steel bars (Salas et al., 2002).

Specimen Autopsy Increment Rating

$$= \sum_{k=1}^{n} \left[\sum_{i=1}^{j} \left(R_{BarTop,i} + R_{BarBot,i} \right) \right] \tag{3.3}$$

n = Total number of bars in the specimen

k = Bar number, from 1 to k

j = Total number of intervals in Bar k

i = interval number, from 1 to j

$R_{BarTop,i}$ = Top-half corrosion rating in interval i of Bar k

$R_{BarBar,i}$ = Bottom-half corrosion rating in interval i of Bar k

3.3.4.1.2 Modified Autopsy Increment Rating Method Used in This Study. Some modifications were made to the method developed by Salas et al. (2002) before it was implemented in this study. Adjustments were made to both the rating values as well as the descriptions listed in Figure 3.9. First, the R^2 rating value used for the most severe corrosion category, loss of cross-sectional area, was replaced with a rating of 16. This value was chosen to simplify the rating method by forgoing the need to estimate the cross-sectional area reduction in percent. Instead, increments displaying area reduction were assigned a rating of 16, which continues the pattern of doubling the rating for each successive increase in the extent of corrosion. The bar examinations were completed by visual assessment only, without the use of a cleaning pad, so references to use of a cleaning pad have been removed from the category descriptions. The modified rating scale used in this study is shown in Figure 3.10 with photographs included to illustrate representative samples of each corrosion category.

To implement the Autopsy Increment Rating Method, each bar was divided into 2 in. increments along the length of bar contained in the concrete. During examination, the bars were placed on a display board with the increment locations designated on yardsticks fastened parallel to the longitudinal bars. Photographs were taken of the top and bottom halves of both the top and bottom mats of reinforcement. For example, Figure 3.11 shows the display board illustrating the increment divisions for the top half of the top mat of Specimen No. 22 in Group 11.

As shown in Figure 3.11, the 24 in. length of each longitudinal bar was divided into 12 increments. Similarly, each 6 in. transverse bar was divided into 3 increments. A rating was assigned to both the top-half and bottom-half of each increment, so each longitudinal bar was assigned a total of 24 increment ratings, while each transverse bar was assigned a total of 6 increment ratings.

Typically, the total specimen corrosion rating was calculated using the summation equation developed by Salas et al. (2002) as shown previously by Equation 3.3. However, during examination, corrosion was often observed on the ends of the longitudinal bars protruding from the concrete, despite having been sealed with both Rust-Oleum Stops Rust paint and Sikagard 62 (Figure 3.12). As discussed previously in Section 3.2.2.2, corrosion of this exposed steel is considered a source of error because it causes an increase in the electrical measurements, resulting in an overestimation of the level of corrosion activity within the specimen.

To quantify this error, increment ratings were assigned to both the top and bottom halves of each of the eight (8) bar ends protruding from the concrete. The

Rating	Meaning	Description	Sample Photograph
0	No Corrosion	No evidence of corrosion.	
1	Discoloration	Discoloration from original color.	
2	Light	Surface corrosion on less than one half of the interval, no pitting.	
4	Moderate	Surface corrosion on more than one half of the interval, no pitting.	
8	Pitting	Pits visible to unaided eye.	
16	Loss of Cross-Sectional Area	Visible reduction in bar cross-sectional area due to corrosion.	

Figure 3.10 Rating scheme for Autopsy Increment Rating Method.

total error rating for each specimen was calculated by the summation of the ratings assigned to the top and bottom halves of each of the eight (8) protruding bar ends (Equation 3.4).

Figure 3.11 Reinforcement display board with designated increment division.

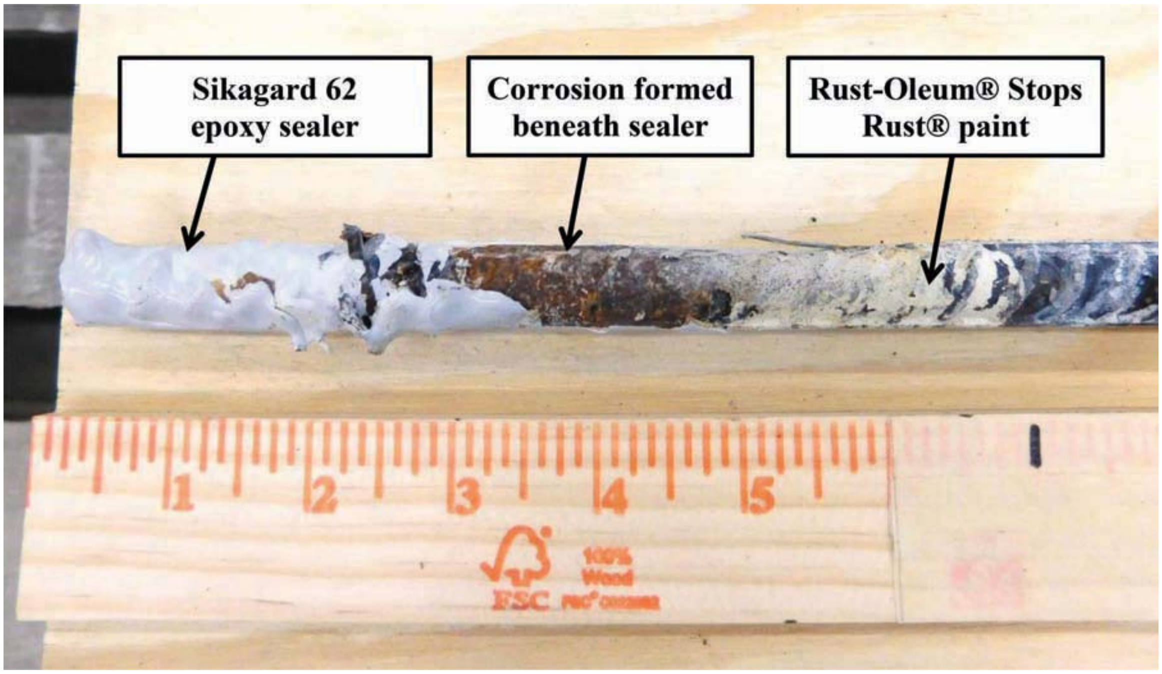


Figure 3.12 Corrosion on end of longitudinal bar.

$$Error_{\text{Increment Rating Method}} = \sum_{i=1}^{8} \left(R_{\text{Bar End Top},i} + R_{\text{Bar End Bot},i} \right) \quad (3.4)$$

i = Bar end number, from 1 to 8

$R_{BarEndTop,i}$ = Top-half corrosion rating of bar end i

$R_{BarEndBot,i}$ = Bottom-half corrosion rating of bar end i

During examination of the bars, it was found that, in some cases, corrosion had initiated at the protruding ends of the bars and spread along the bar to portions of the bar that were inside the concrete. Taking this into consideration, corrosion observed on the top or bottom of the bars in interior increments No. 1 and 12, located adjacent to the front and back faces of the specimen, was examined carefully to identify the source of deterioration. If the corrosion in increment No. 1 or 12 appeared to be a result of corrosion spreading from the crack location at the interior of the specimen (Case 1), then Equations 3.3 and 3.4 were used as described previously. However, if the corrosion in a given increment No. 1 or 12 appeared to be a result of corrosion spread inward from the outside of the specimen (Case 2), then the respective increment rating was not included as part of the Specimen Autopsy Increment Rating, but rather was included as part of the error calculated for the specimen.

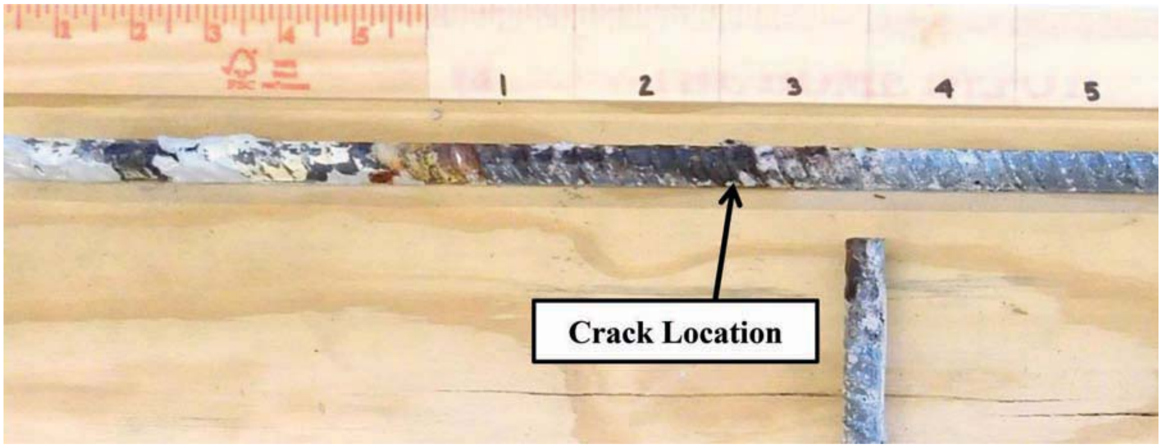


Figure 3.13 Corrosion on bottom half of increment No. 1.

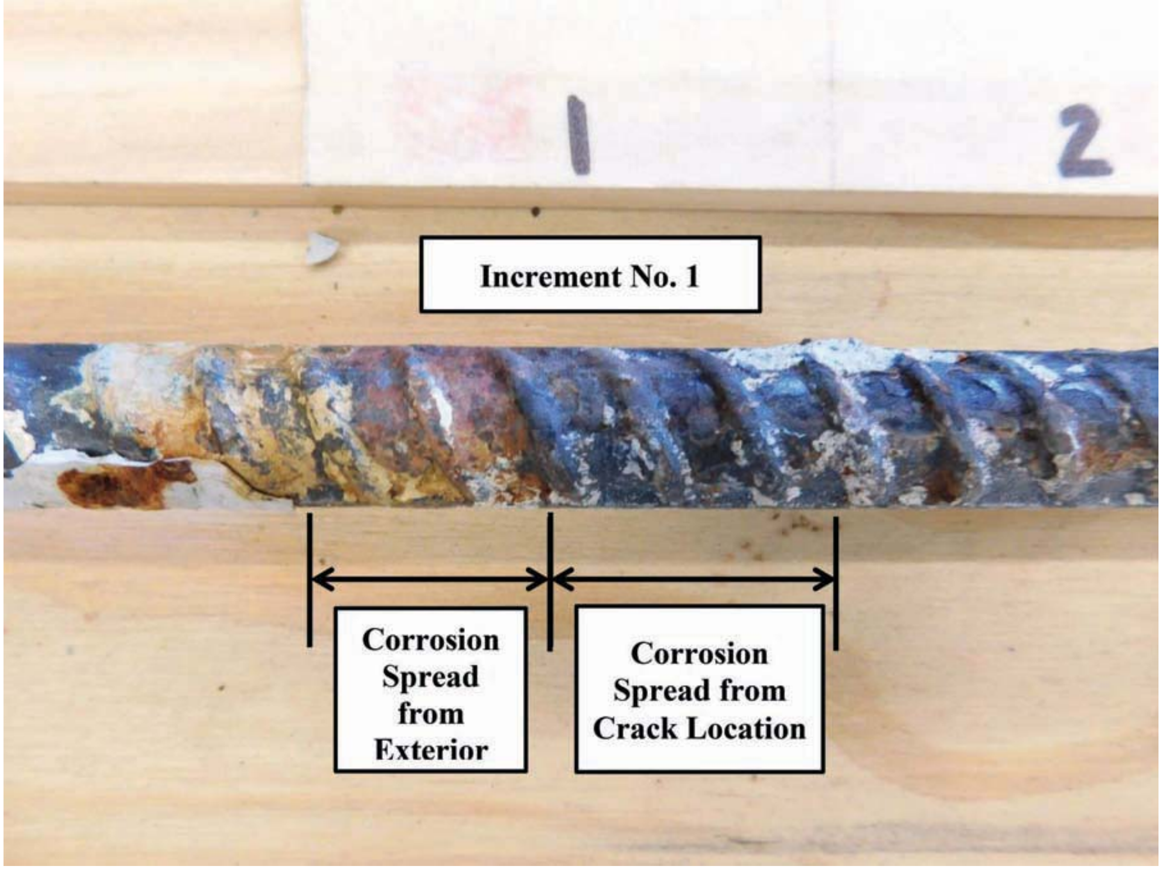


Figure 3.14 Close-up of corrosion on bottom half of increment No. 1.

The top and bottom halves of the bottom left longitudinal bar in Specimen No. 22 of Group 11 provide an example. The bottom half of the bar (Figure 3.13 and Figure 3.14) shows Case 1, where over half the corrosion in increment No. 1 appears to be a result of the crack that formed in increment No. 3. However, on the top half (Figure 3.15), the corrosion in increment No. 1 appears to have originated on the exposed steel outside the specimen, an example of Case 2.

Figure 3.16 shows the calculation of the Specimen Autopsy Increment Rating and Error for Specimen No. 22. Specifically, it displays a color-coded representation of the calculations of the interior increment rating (blue) and the error (red) for the bottom left

Figure 3.15 Corrosion on top half of increment No. 1.

longitudinal bar of Specimen No. 22. On the top half, the rating for increment No. 1 is included in the sum of the bar error ratings. On the bottom half, the rating for increment No. 1 is included in the sum of the bar interior corrosion rating. The interior corrosion rating for the bottom left bar is added to that of the other bars to calculate the Specimen Autopsy Increment Rating. Similarly, the error rating for the bar is summed with the error ratings of the other longitudinal bars to calculate the Specimen Error.

3.3.4.1.3 Autopsy Increment Rating Method Used by Pollastrini (2013). The Salas et al. (2002) method was also used by Pollastrini (2013) during the preliminary autopsy completed after 617 test days. First, the ratings were assigned using the scale shown in Figure 3.10, and the Specimen Autopsy Increment Rating was calculated using Equation 3.3. However, Pollastrini then generated what was referred to as a Generalized Corrosion Rating, which divided the Specimen Autopsy Increment Rating by the increment length of 2 in. as shown in Equation 3.5. Pollastrini's results were reported using this Generalized Corrosion Rating. Because Pollastrini reported results using the Generalized Corrosion Rating and this study uses the original Specimen Autopsy Increment Rating, the autopsy ratings developed by Pollastrini are not referenced in the results of this study. However, his ratings can be simply multiplied by two (2) which can provide for relative comparison. It should be noted that while this rating method attempts to be objective, there still remains subjectivity, as the assigned ratings are based on the judgment of the investigator.

Generalized Corrosion Rating

$$= \frac{1in.}{l} \sum_{k=1}^{n} \left[\sum_{i=1}^{j} \left(R_{BarTop,i} + R_{BarBot,i} \right) \right] \tag{3.5}$$

l = Length of increment (in.)

n = Total number of bars in the specimen

k = Bar number, from 1 to k

j = Total number of intervals in Bar k

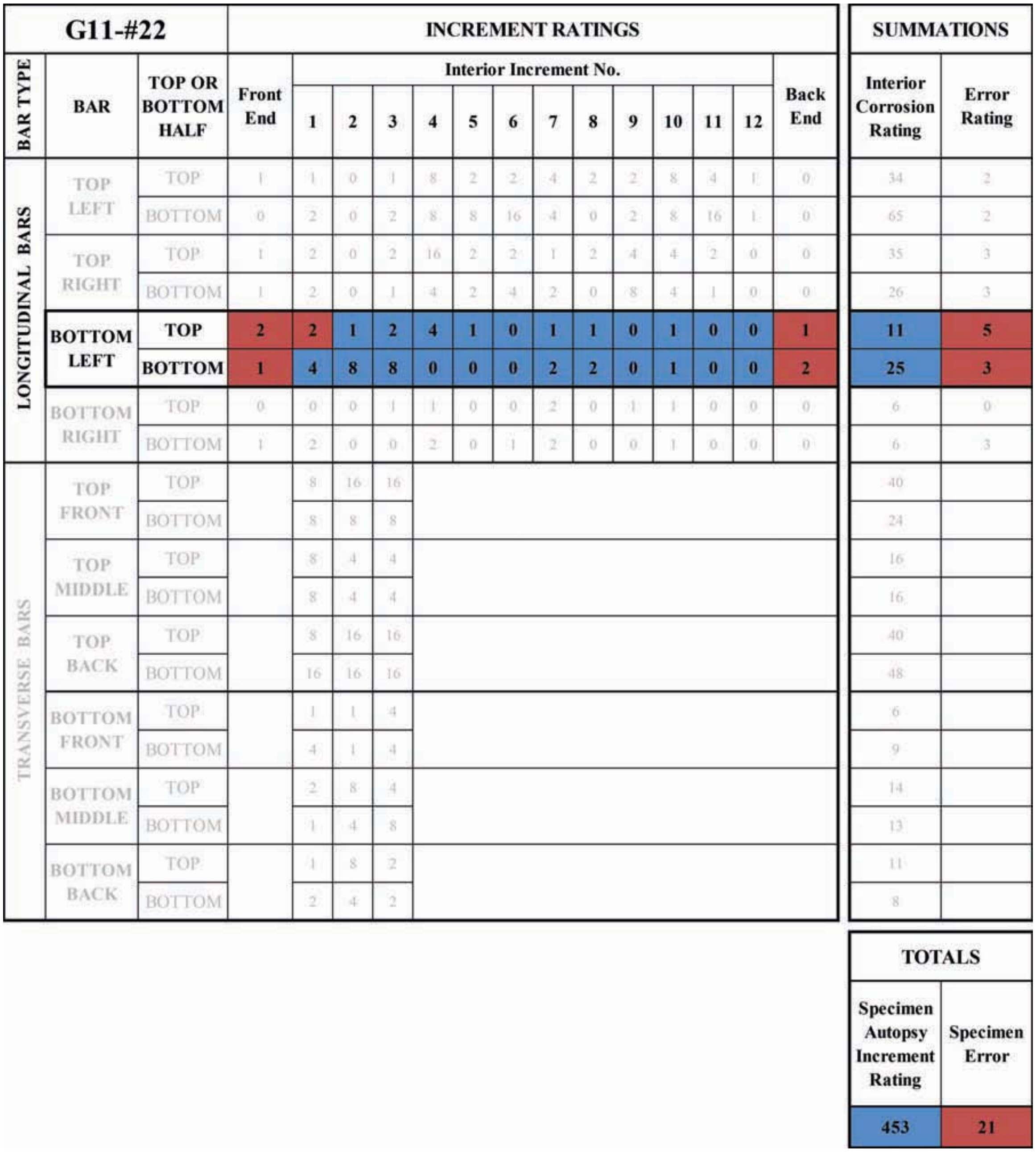
i = interval number, from 1 to j

$R_{BarEndTop,i}$ = Top-half corrosion rating in interval i of Bar k

$R_{BarEndBot,i}$ = Bottom-half corrosion rating in interval i of Bar k

3.3.4.2 Autopsy Crack Location Rating Method. Because corrosion typically occurs along the reinforcement at the location of cracks, a simplified autopsy rating scheme was developed to quantify the severity of corrosion that occurred at each crack location instead of at numerous incremental locations and is especially useful when evaluating crack repair materials. This method was developed using a rating scale of 0 to 10 shown in Figure 3.17.

A rating was assigned to each transverse bar and each crack location along the longitudinal bars. Additionally, the eight (8) protruding ends of the longitudinal bars were also rated to quantify the electrical data error contribution of the exposed steel. Unlike the Autopsy Increment Rating Method in which ratings are assigned to both the top half and bottom half of the bar



G11-#22			INCREMENT RATINGS														SUMMATIONS	
BAR TYPE	BAR	TOP OR BOTTOM HALF	Front End	Interior Increment No.												Back End	Interior Corrosion Rating	Error Rating
				1	2	3	4	5	6	7	8	9	10	11	12			
LONGITUDINAL BARS	TOP LEFT	TOP	1	1	0	1	8	2	2	4	2	2	8	4	1	0	34	2
		BOTTOM	0	2	0	2	8	8	16	4	0	2	8	16	1	0	65	2
	TOP RIGHT	TOP	1	2	0	2	16	2	2	1	2	4	4	2	0	0	35	3
		BOTTOM	1	2	0	1	4	2	4	2	0	8	4	1	0	0	26	3
	BOTTOM LEFT	**TOP**	**2**	**2**	**1**	**2**	**4**	**1**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**11**	**5**
		BOTTOM	**1**	**4**	**8**	**8**	**0**	**0**	**0**	**2**	**2**	**0**	**1**	**0**	**0**	**2**	**25**	**3**
	BOTTOM RIGHT	TOP	0	0	0	1	1	0	0	2	0	1	1	0	0	0	6	0
		BOTTOM	1	2	0	0	2	0	1	2	0	0	1	0	0	0	6	3
TRANSVERSE BARS	TOP FRONT	TOP		8	16	16											40	
		BOTTOM		8	8	8											24	
	TOP MIDDLE	TOP		8	4	4											16	
		BOTTOM		8	4	4											16	
	TOP BACK	TOP		8	16	16											40	
		BOTTOM		16	16	16											48	
	BOTTOM FRONT	TOP		1	1	4											6	
		BOTTOM		4	1	4											9	
	BOTTOM MIDDLE	TOP		2	8	4											14	
		BOTTOM		1	4	8											13	
	BOTTOM BACK	TOP		1	8	2											11	
		BOTTOM		2	4	2											8	

TOTALS	
Specimen Autopsy Increment Rating	Specimen Error
453	21

Figure 3.16 Example calculation of Specimen Autopsy Increment Rating and Error.

at each interval, only one rating is assigned at each of the aforementioned locations.

Prior to autopsy of a cracked specimen, the distance was measured from the front surface of the concrete specimen to each crack location in each specimen. The identified crack locations were then sketched onto diagrams of the top and bottom mats. During examination, the longitudinal bars were given ratings from 0 to 10 at each crack location. Each of the transverse bars was also assigned a rating. The protruding ends of the longitudinal bars were evaluated and assigned a rating. Lastly, if there was corrosion noted on the longitudinal bars at the interior of the specimen, as a result of corrosion spreading inward from the protruding ends of the bars, then that location was also assigned a rating. An example of the rating assignments for a cracked specimen is presented in Figure 3.18.

Because the specimens in Groups 20U to 30U do not have cracks, the ratings on the longitudinal bars were assigned to 6 in. intervals along the bars. Furthermore, the transverse bars were not removed from the uncracked specimens, so an estimation of their corrosion rating was made by examining the ends of the transverse bars exposed during autopsy, as shown in Figure 3.19. The protruding ends of the longitudinal bars were rated to provide an electrical data error estimate for each specimen.

Rating	Description	Sample Photograph
0	No evidence of corrosion.	
1	Localized area of discoloration	
2	Discoloration on only the top or bottom half of the bar	
3	Light surface corrosion on both halves of the bar	
4	Surface corrosion spread on both the top and bottom halves of the bar	
5	Surface corrosion on over half the bar circumference	
6	Moderate corrosion on over half the bar circumference **or** Localized pitting	

Figure 3.17 Rating scheme for Autopsy Crack Location Rating Method.

Again, if corrosion was observed on the longitudinal bars within the specimen that appeared to have spread inward from the exterior of the specimen, a rating was also assigned at that location. Figure 3.20 provides an example of ratings assigned to an uncracked specimen.

The overall Specimen Autopsy Crack Location Rating for each specimen was calculated by summing the ratings of the longitudinal and transverse bars (shown in Figure 3.18 and Figure 3.20 as blue and green) in both the top and bottom mats of reinforcement (Equation 3.6).

7	Moderate corrosion on over half the bar circumference with localized pitting	
8	Moderate corrosion on entire bar circumference **or** Pitting on over half the surface area	
9	Moderate loss of cross-sectional area	
10	Severe loss of cross-sectional area	

Figure 3.17 (cont.) Rating scheme for Autopsy Crack Location Rating Method.

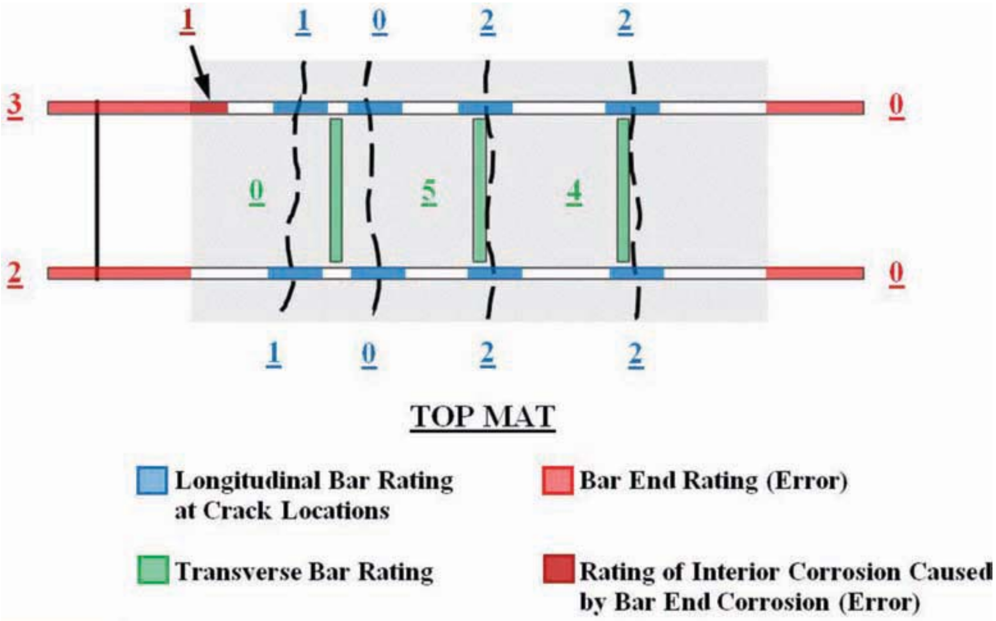


Figure 3.18 Example Autopsy Crack Location Rating (cracked specimen).

The error due to corrosion of exposed steel was calculated by summing the ratings of each of the eight (8) protruding ends of the longitudinal bars (shown in Figure 3.18 and Figure 3.20 as light red) and the ratings of any interior corrosion caused by exterior corrosion (shown in Figure 3.18 and Figure 3.20 as dark red) as shown in Equation 3.7.

Autopsy Crack Location Rating

$$= \sum_{i=1}^{n} \left(R_{BarLong,i}\right) + \sum_{j=1}^{6} \left(R_{BarTrans,j}\right) \qquad (3.6)$$

n = Number of longitudinal bar rating locations
i = Longitudinal bar rating location number
j = Transverse bar number, from 1 to 6
$R_{BarLong,i}$ = Longitudinal bar corrosion rating at location i
$R_{BarTrans,j}$ = Transverse bar corrosion rating of Bar j

$Error_{CrackLocationRating}$

$$= \sum_{i=1}^{8} \left(R_{EndError,i}\right) + \sum_{j=1}^{n} \left(R_{InteriorError,j}\right) \qquad (3.7)$$

i = Bar end number, from 1 to 8
n = Number of interior error locations
j = Interior error location number from 1 to n
$R_{EndError,i}$ = Corrosion rating of bar end i
$R_{InteriorError,j}$ = Corrosion rating of interior error location j

Figure 3.19 End of transverse bar exposed during uncracked specimen autopsy.

3.4 Chloride Penetration

Chloride penetration testing was completed to further the investigation of the three deck sealers' effectiveness in reducing the intrusion of salt water in the concrete. After the deck sealer specimens were autopsied, a rotary drill was used to collect concrete dust samples at incremental depths from the top surface of the specimen to a depth of 2.5 in. A James Instruments Chlorimeter CL-3000 test system was used to measure the percent chloride content by weight of concrete at each depth increment. Chloride penetration profiles were developed for both cracked and uncracked specimens with deck sealers. The chloride penetration profiles were also developed for specimens opened during the preliminary autopsy of 2013.

3.4.1 Collection of Concrete Dust Samples

A rotary drill with a 3/4 in. drill bit was used to generate concrete dust samples in 0.25 in. depth increments from the top surface of the specimen to a depth 2.5 in., the depth of the bottom of the longitudinal bars in the top mat. Therefore, the bottom four 0.25 in. increments of concrete are at the level of the transverse and longitudinal bars in the top mat. The chloride content at the depth of the reinforcement is expected to correlate with the amount of corrosion activity observed on the steel.

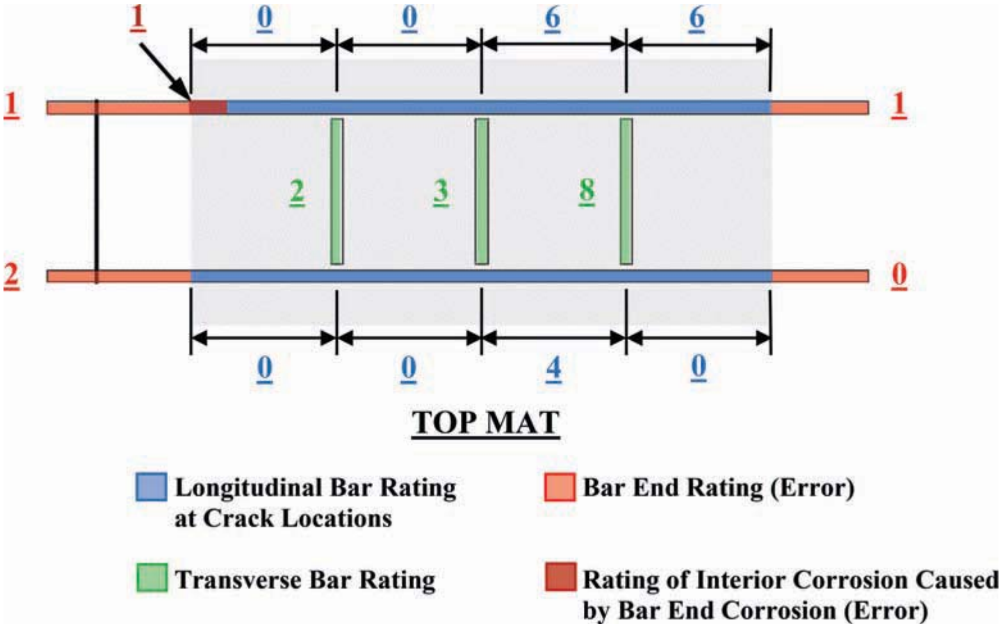


Figure 3.20 Example Autopsy Crack Location Rating (uncracked specimen).

Figure 3.21 Drilling specimens to collect chloride test samples.

Figure 3.22 James Instruments Chlorimeter CL-3000 test system.

Three holes were drilled in each specimen to collect the dust at each depth increment as shown in Figure 3.21. It was necessary to drill three holes to collect enough dust to support a minimum of two chlorimeter tests. Given the non-homogeneity of concrete, collecting and mixing the dust from three holes was also needed to generate a representative test sample. After drilling each incremental depth in all three holes, a brush was used to collect the dust into a resealable plastic bag. Between increments, the top surface of the specimen, the holes, and the collection brush were cleaned with compressed air, and the drill bit was wiped with a rag to avoid cross-contamination.

3.4.2 Chlorimeter Test System

The James Instruments Chlorimeter CL-3000 was used to determine the percent chloride content by weight of concrete of each concrete dust sample to generate chloride penetration profiles for each specimen tested. The test system includes the chlorimeter with the attached electrode, a bottle of electrode wetting agent, bottles of extraction liquid, and calibration liquids. Prior to testing, the chlorimeter was calibrated using five (5) manufacturer-provided calibration liquids, each of a different chloride concentration.

To prepare a sample for testing, the dust collected at a given depth was mixed thoroughly to blend the dust collected from the three holes. For each trial, a scale was used to prepare a 3-gram sample of dust to be dissolved in 20 milliliters (mL) of mildly acidic extraction liquid. After shaking the test bottle to fully dissolve the sample, the tip of the electrode was placed into the liquid to measure the electrochemical reaction (Figure 3.22). The chlorimeter displayed the percent chloride by weight of concrete. Finally, the electrode was cleaned with distilled water before testing the next sample. Caution was exercised to avoid cross-contamination of the samples during preparation and testing. The chloride penetration profile for a given specimen could be generated after recording the chloride content of each depth increment.

3.5 Deck Sealer Penetration Depth

The penetration depth of deck sealers on uncracked specimens was measured to determine if there is a correlation between performance and penetration depth. The specimens studied included the sealed uncracked specimens in Groups 20U to 22U and 24U to 29U. Therefore, sealer penetration depths were determined for specimens with and without surface preparation. Penetration depth was also evaluated for specimens with sealed surfaces that were subsequently sandblasted to simulate traffic wear. Autopsied specimens were split into segments to provide a broken cross-section with a width of 3.5 in. for examination.

For the two silane deck sealers, MasterProtect H 440 HZ and MasterProtect H 400, the samples were first oven-dried at 194°C for three days. Each cross-section was then sprayed with water to reveal the area of sealer penetration. Because the sealers are hydrophobic, the area with the sealer remained dry and light-colored, while the area without sealer absorbed the water and turned to a darker grey (Figure 3.23). The depth of penetration was then measured using a caliper at a minimum of six locations along the 3.5 in. width of the cross-section.

The penetration of linseed oil was not visible when the cross-section was sprayed with water; therefore, another approach was required to determine its penetration depth. It was found that the use of ultraviolet light in a dark room brightly illuminated the area of the cross-section where the sealer had penetrated (Figure 3.24). A caliper was used to obtain a minimum

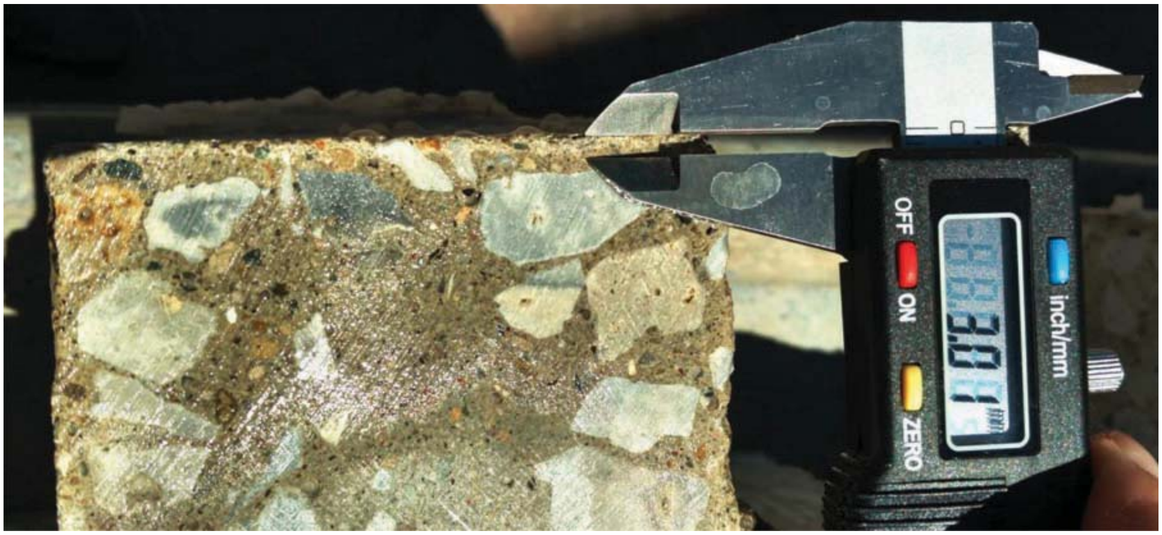


Figure 3.23 Use of a caliper to measure deck sealer penetration depth.

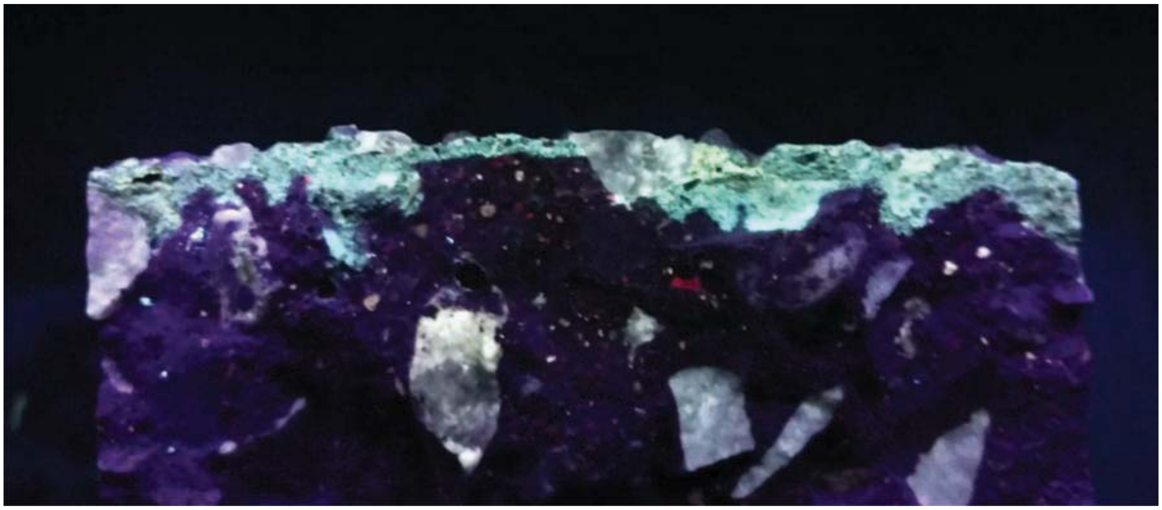


Figure 3.24 Linseed oil penetration in an uncracked specimen with surface preparation.

of six penetration measurements across the 3.5 in. width of the examined cross-section.

4. RESULTS AND DISCUSSION

4.1 Introduction

After 1600 test days, the relative performance of the investigated test variables was evaluated by comparing the results from a variety of data collection methods. Section 4.2 provides an introduction to the types of graphs and charts used to present the collected data. Sections 4.3 and 4.4 investigate the performance of sealers on cracked and uncracked specimens by correlating the electrical measurements and the results of both autopsy rating methods. This chapter also includes the results of applying deck sealer to an actively-corroding control specimen. Finally, an analysis of chloride penetration profiles and deck sealer penetration depths is presented.

4.2 Analysis Overview and Test Results

Each comparison of variables is supported using a variety of figures. Each analysis includes a graph of the electrical activity recorded for each specimen over a period of 1600 days. Bar charts are used to present the electrical measurements recorded at 617 days and 1600 days, as well as the results of each autopsy rating method.

4.2.1 Electrical Activity History

Electrical activity recorded over 1600 days for a series of specimen groups are presented in graphs such as that shown in Figure 4.1. In this figure, the total corrosion in coulombs is plotted versus time in days. In the legend, the first specimen of each group shows the group number, the specimen number, and an abbreviated description of the group's test variables. The legend abbreviates "MasterProtect" as "MP." For example, Specimen No. 11 in Group 3 was treated with both a crack and

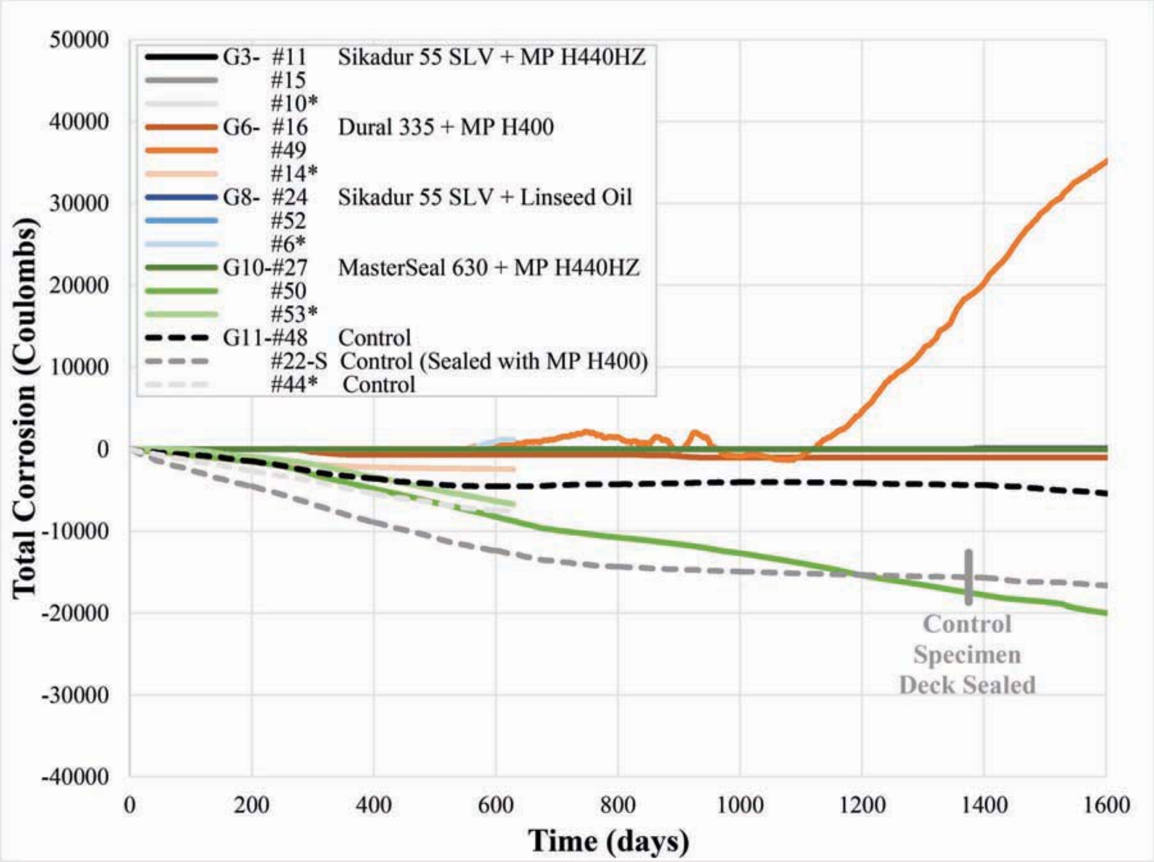


Figure 4.1 Example graph of electrical activity history.

deck sealer, resulting in the designation, "G3-#11 Sikadur 55 SLV + MP H440HZ."

The three specimens of each group are shown as three shades of a given color family. The specimens of the control group are shown as dashed lines. One specimen in each unsealed control group is labeled at 1375 days to denote the date that deck sealer was applied to that specific specimen. In the legend, these sealed control specimens are designated by "-S" after the specimen number. Furthermore, the data for specimens autopsied in 2013 by Pollastrini are truncated after 617 days because they were disconnected from the datalogger at the time of autopsy. Specimens analyzed during the preliminary autopsy in 2013 are designated throughout this report by an asterisk (*).

The specimens typically display negative values of total corrosion. Negative values signify the presence of macrocell corrosion in which the flow of electrons between the two mats of reinforcement causes corrosion at an anode in the top mat. However, a select number of specimens, such as Specimen No. 49 in Figure 4.1, experienced a reversal in the flow of current resulting in positive values of total corrosion, which indicates that corrosion is occurring in the bottom mat.

4.2.2 Intermediate Electrical Measurements (617 Days)

The bar chart presented in Figure 4.2 shows the magnitude of total corrosion measured for all 90 specimens at 617 days, the last day of data acquisition before the preliminary autopsy by Pollastrini in 2013. The specimens with typical negative total corrosion values are shown in blue, while those with positive total corrosion values are shown in green. The measurement is shown in red if there was no corrosion observed in the interior of the specimen during autopsy. In these cases, electrical activity was recorded because corrosion occurred on the exposed ends of the longitudinal bars.

The electrical measurements at 617 days are studied for two reasons. First, it is the last day at which electrical data could be recorded from all three specimens of each group. In addition, the data trends for a particular variable at 617 days can be compared to trends at 1600 days to identify whether the additional test days were necessary to establish the final data trends.

4.2.3 Final Electrical Measurements (1600 Days)

Because one-third of the specimens were disconnected at 617 days for the preliminary autopsy, only the remaining 60 specimens were monitored until 1600

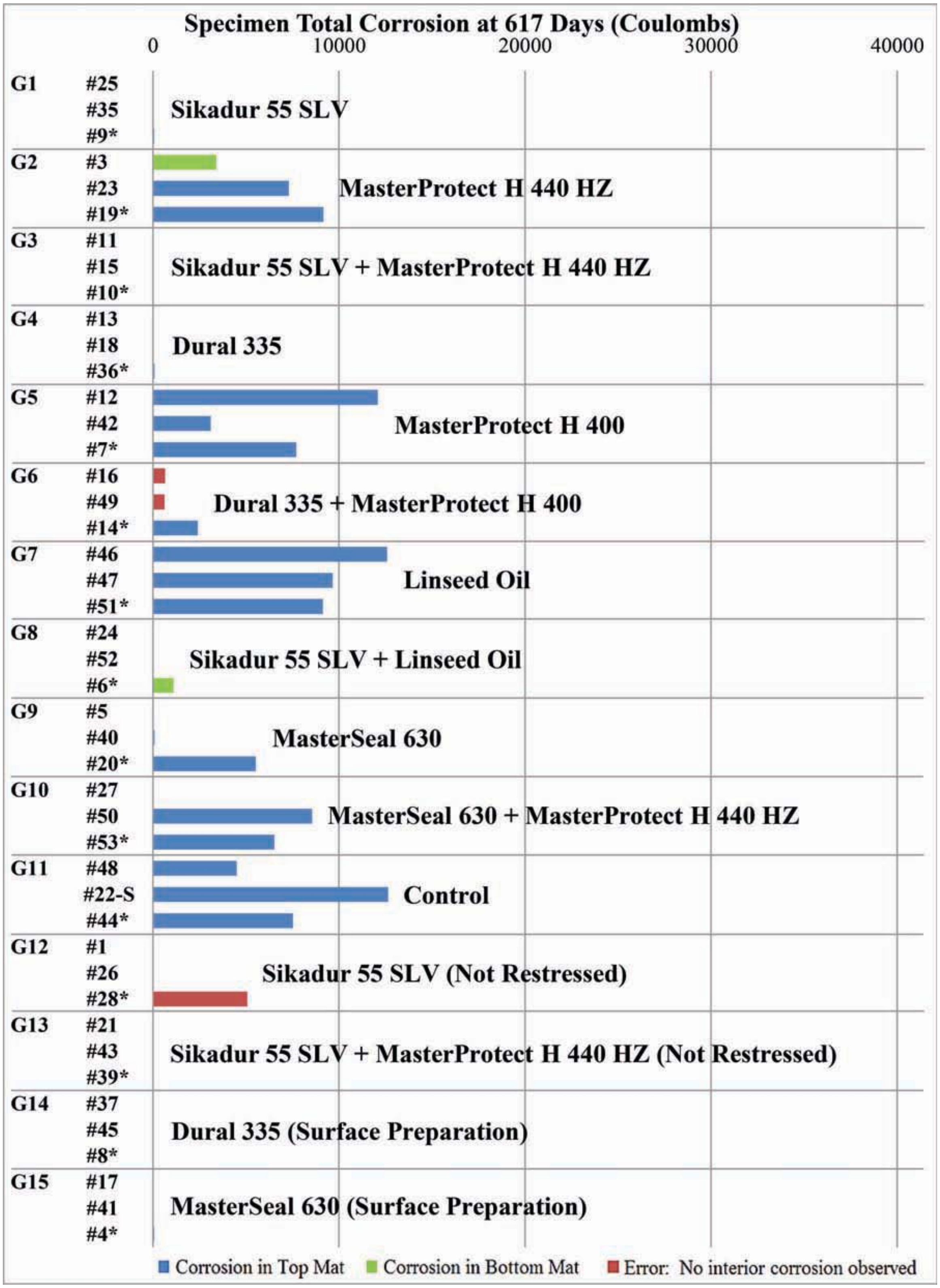


Figure 4.2 Specimen electrical activity at 617 days.

days. The magnitudes of the total corrosion measured for each specimen at 1600 days is presented in Figure 4.3. The colors used in this figure designate the same conditions as those described in Section 4.2.2 for Figure 4.2, and this color scheme is used throughout this chapter.

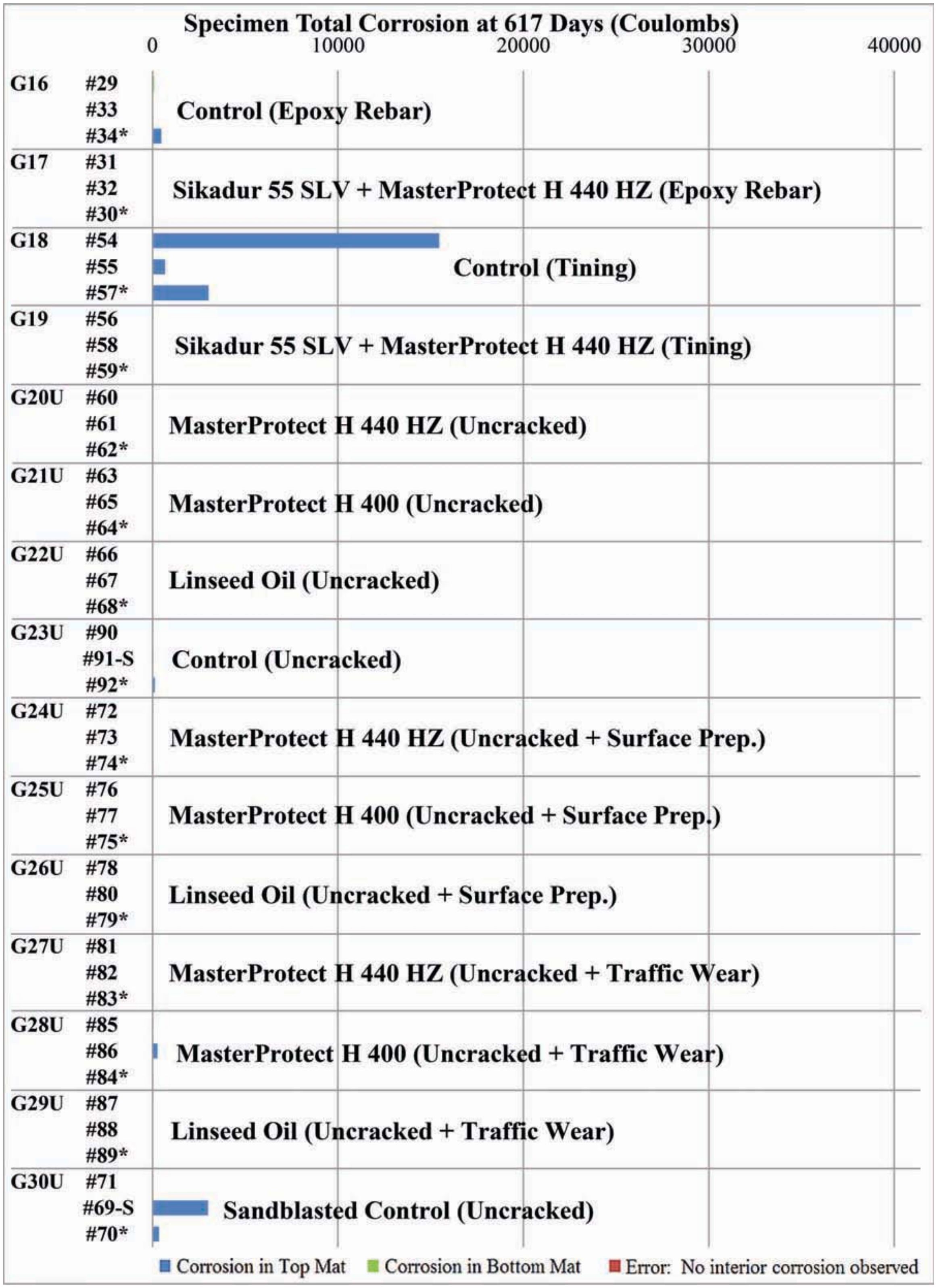


Figure 4.2 (cont.) Specimen electrical activity at 617 days.

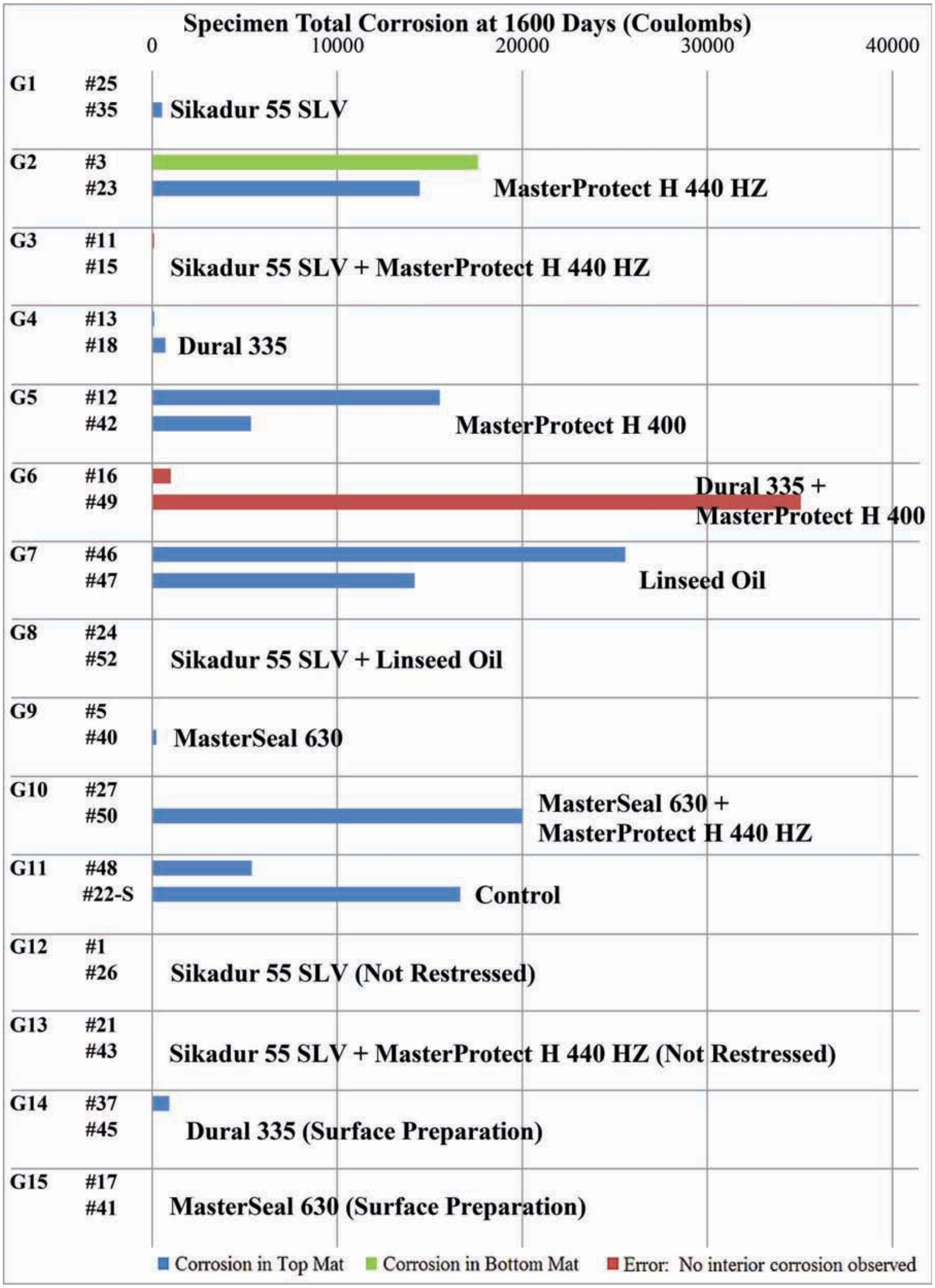


Figure 4.3 Specimen electrical activity at 1600 days.

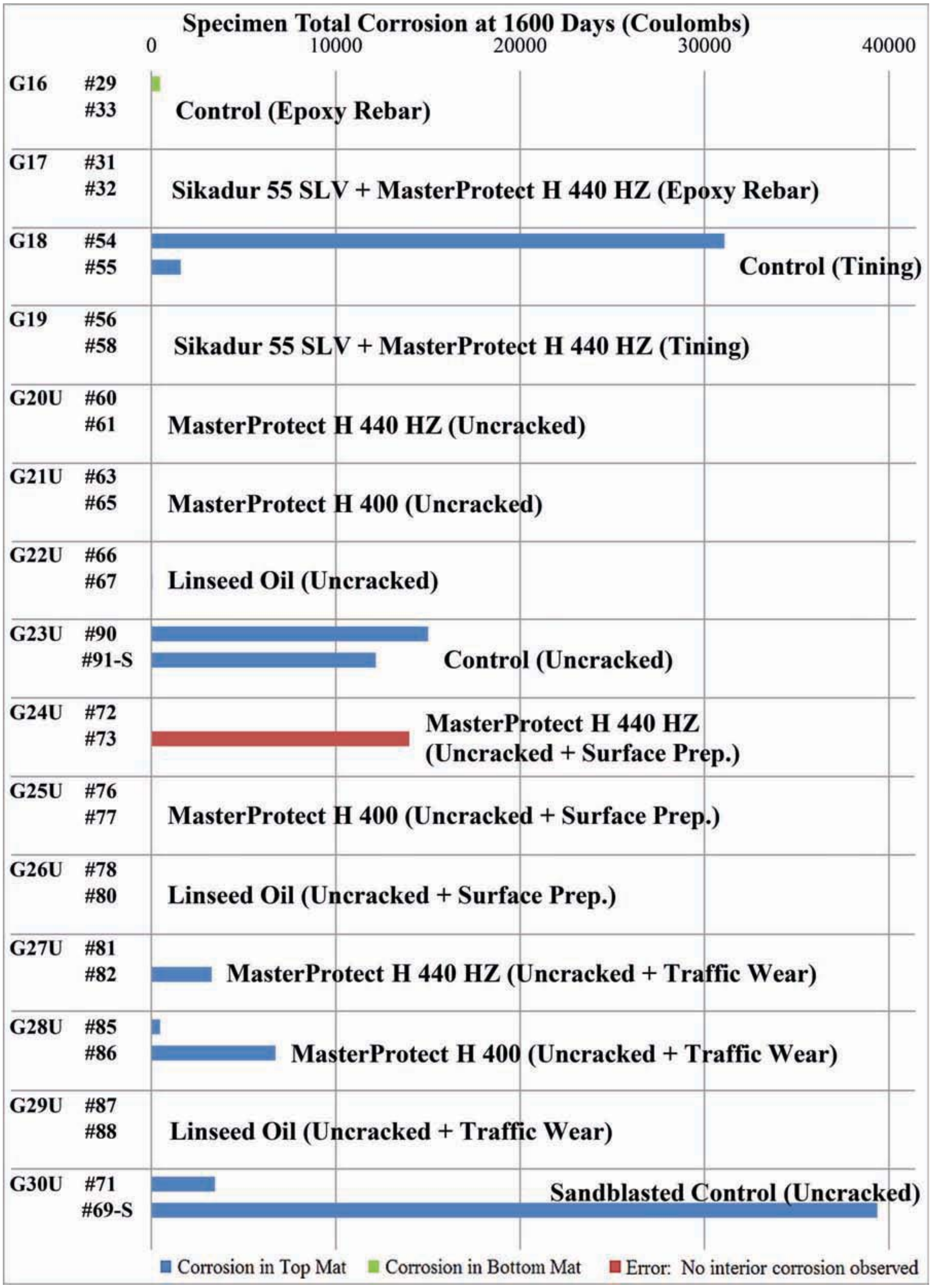


Figure 4.3 **(cont.)** Specimen electrical activity at 1600 days.

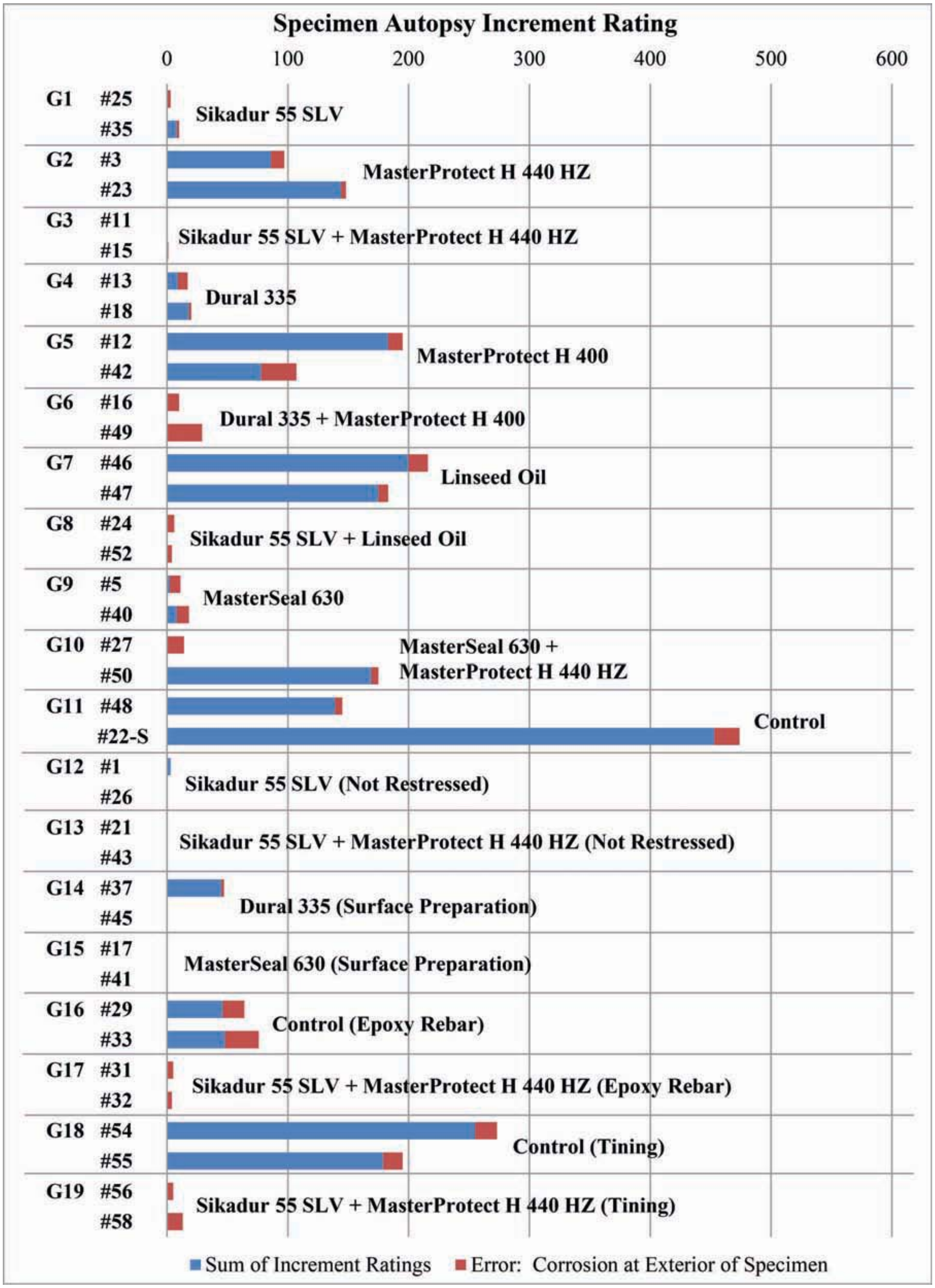


Figure 4.4 Specimen Autopsy Increment Ratings for cracked specimens.

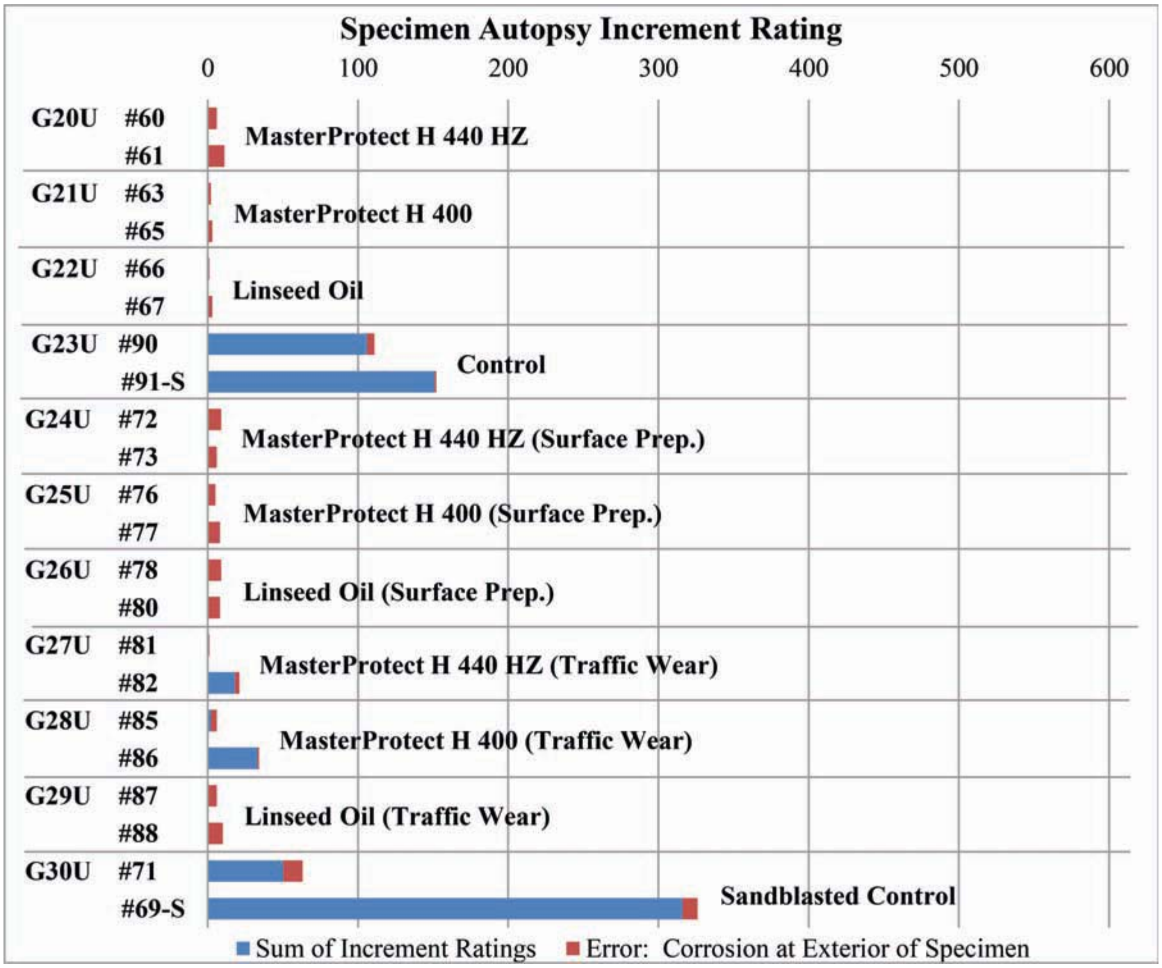


Figure 4.5 Specimen Autopsy Increment Ratings for uncracked specimens.

4.2.4 Specimen Autopsy Increment Ratings

The Specimen Autopsy Increment Ratings for cracked and uncracked specimens autopsied after 1600 days are shown in Figure 4.4 and Figure 4.5, respectively. The Specimen Autopsy Increment Ratings calculated as outlined in Section 3.3.4.1.2 are shown in blue and represent corrosion occurring within the specimen as a result of salt water ingress at cracks and through the concrete surface. The red bars represent additional corrosion observed that appeared to occur as a result of corrosion of the exposed steel. As discussed previously, corrosion of the exposed steel contributes to the measured electrical current, resulting in an overestimation of the total corrosion values presented in Figure 4.2 and Figure 4.3. In Sections 4.3 and 4.4, these red error bars allow the electrical measurements to be correlated with autopsy results to determine the source of corrosion in each specimen.

4.2.5 Specimen Autopsy Crack Location Ratings

The Specimen Autopsy Crack Location Rating Method serves as a second method of autopsy ratings. The objective of using a second method is to maintain objectivity in the autopsy evaluations because the ratings are based on visual condition assessments. The ratings obtained using the Specimen Autopsy Crack Location Rating Method for all specimens autopsied at 1600 days are presented in Figure 4.6 (cracked specimens) and Figure 4.7 (uncracked specimens). As in the Specimen Autopsy Increment Rating Method, ratings resulting from exposed steel corrosion are shown in red.

4.3 Cracked Specimens

The specimens in Groups 1 to 19 examine performance of sealers at cracked locations. Groups 1 to 10 were treated with crack sealer, deck sealer, or combinations of crack and deck sealers, while Group 11 served as the control group. The remaining Groups 12 to 19 were used to study the effects of restressing, surface preparation, epoxy reinforcement, and surface tining. The following sections discuss the results of the autopsy rating methods and the recorded electrical activity.

4.3.1 Crack Sealers

The cracked specimens in Groups 1, 4, and 9 were treated with the crack sealers Sikadur 55 SLV, Dural 335, and MasterSeal 630, respectively. Figure 4.8 shows

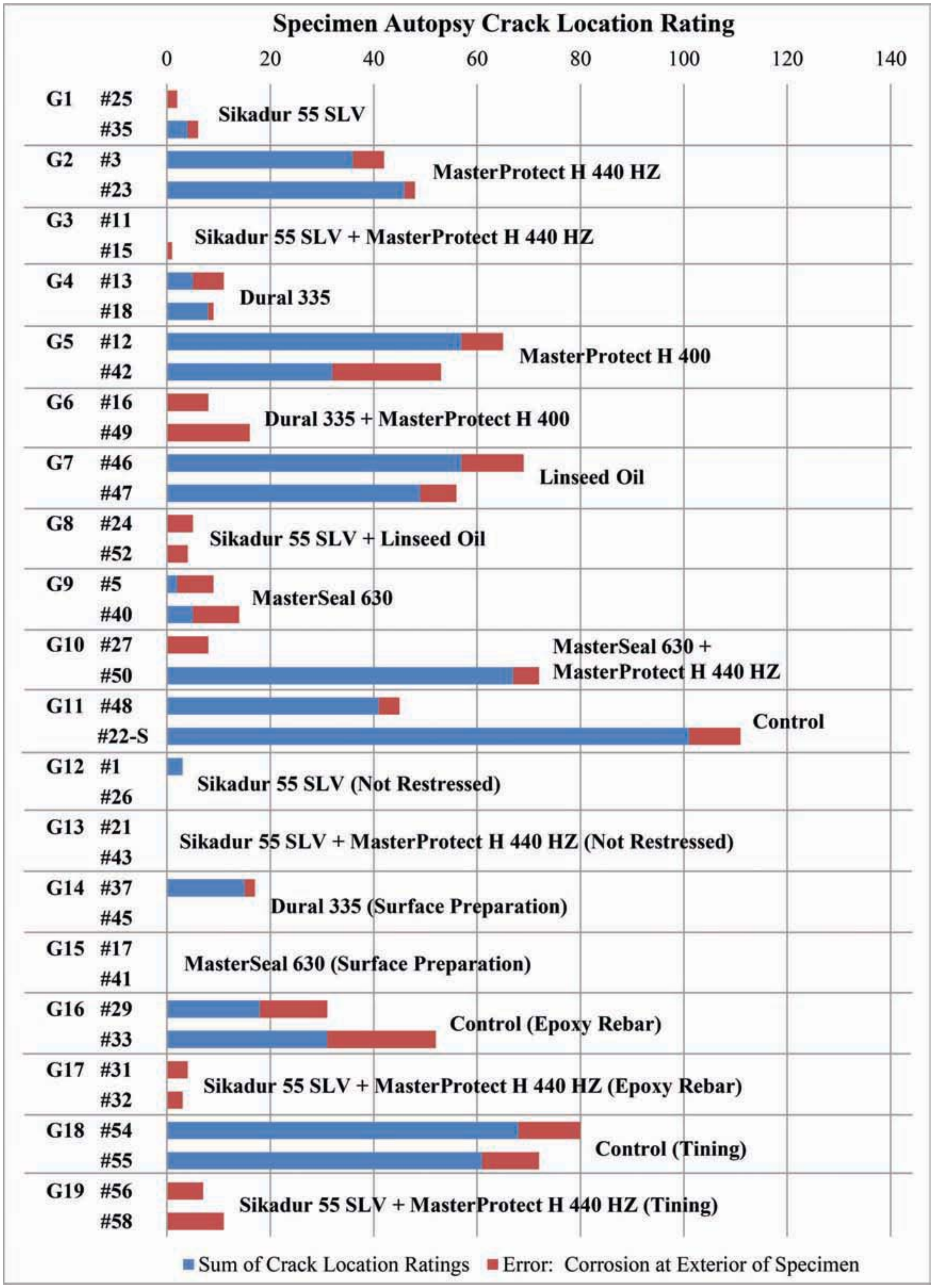


Figure 4.6 Specimen Autopsy Crack Location Rating for cracked specimens.

the electrical activity over 1600 days for the three crack sealer groups as well as cracked control Group 11. The magnitude of total corrosion for each specimen recorded at Day 617, immediately prior to the preliminary autopsy in 2013, is presented in Figure 4.9. At this intermediate stage, all the crack sealed specimens had experienced minimal corrosion as compared with the control group, with the exception of one MasterSeal 630 specimen, No. 20. The preliminary autopsy revealed corrosion at each crack location in the specimen,

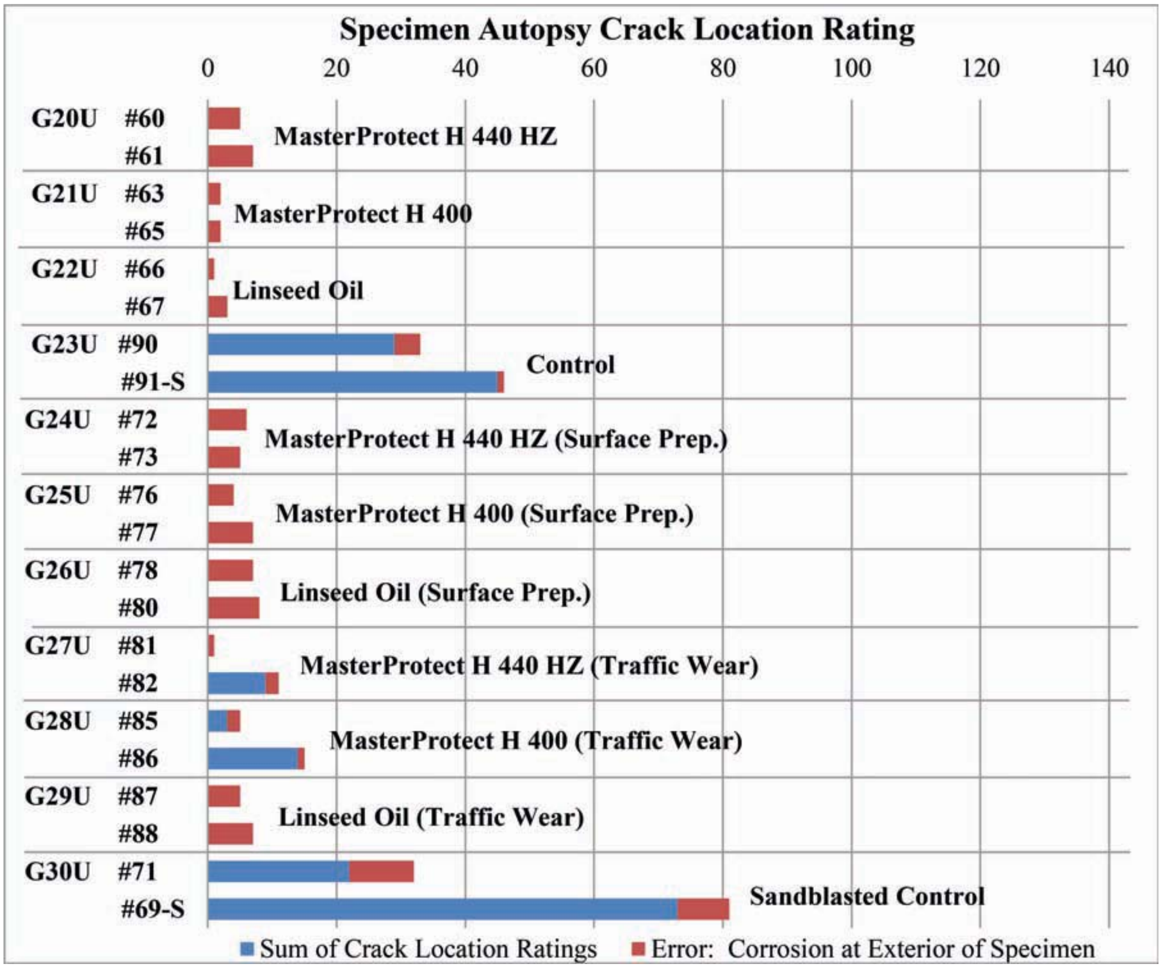


Figure 4.7 Specimen Autopsy Crack Location Rating for uncracked specimens.

resulting in an electrical measurement at 617 days similar to that of the control specimens. Corrosion observed in Specimen No. 20 at each crack location is identified with arrows in Figure 4.11.

One specimen from each group was autopsied in 2013, so the total corrosion values recorded at 1600 days for the two remaining specimens in each group are shown in Figure 4.10. The electrical activity recorded for the crack sealer specimens increased from Day 617 to Day 1600, but it remained below 14 percent of the corrosion level of the control specimens.

The corrosion levels observed during autopsy after 1600 days were tabulated using two rating methods. The crack sealer comparison results from the two methods are shown in Figure 4.12 and Figure 4.13. One of the Sikadur 55 SLV specimens did not exhibit corrosion, while the remaining five treated specimens developed some observable corrosion. The locations of the corrosion in each specimen were carefully documented to identify if corrosion occurred as a result of crack sealer failure or because of general chloride penetration through the surface over 1600 days. Small areas of corrosion were observed only at crack locations, indicating that the corrosion was caused by a localized failure of the crack sealer. Figure 4.14 illustrates the small areas of corrosion observed only at cracked locations in Specimen No. 18.

The autopsy ratings corroborate the results of the electrical activity to conclude that after 1600 days of exposure, Sikadur 55 SLV, Dural 335, and MasterSeal 630 reduced corrosion levels to less than 20 percent of the corrosion in the control specimens. However, it is important to note that one MasterSeal specimen, No. 20, was revealed to have corrosion at all three crack locations after only 617 days of exposure.

4.3.2 Deck Sealers

Groups 2, 5, and 7 consist of cracked specimens treated with only deck sealers to study the deck sealers' ability to prevent salt water penetration at cracks without the prior application of a crack sealer. These three groups were sealed with MasterProtect H 440 HZ, MasterProtect H 400, and linseed oil. The electrical activity recorded for these specimens over 1600 days is compared to control Group 11 in Figure 4.15. Corrosion occurred in all the specimens from the beginning of the experiment and the magnitude of corrosion steadily increased over time. Negative total corrosion values signify the presence of macrocell corrosion, in which the

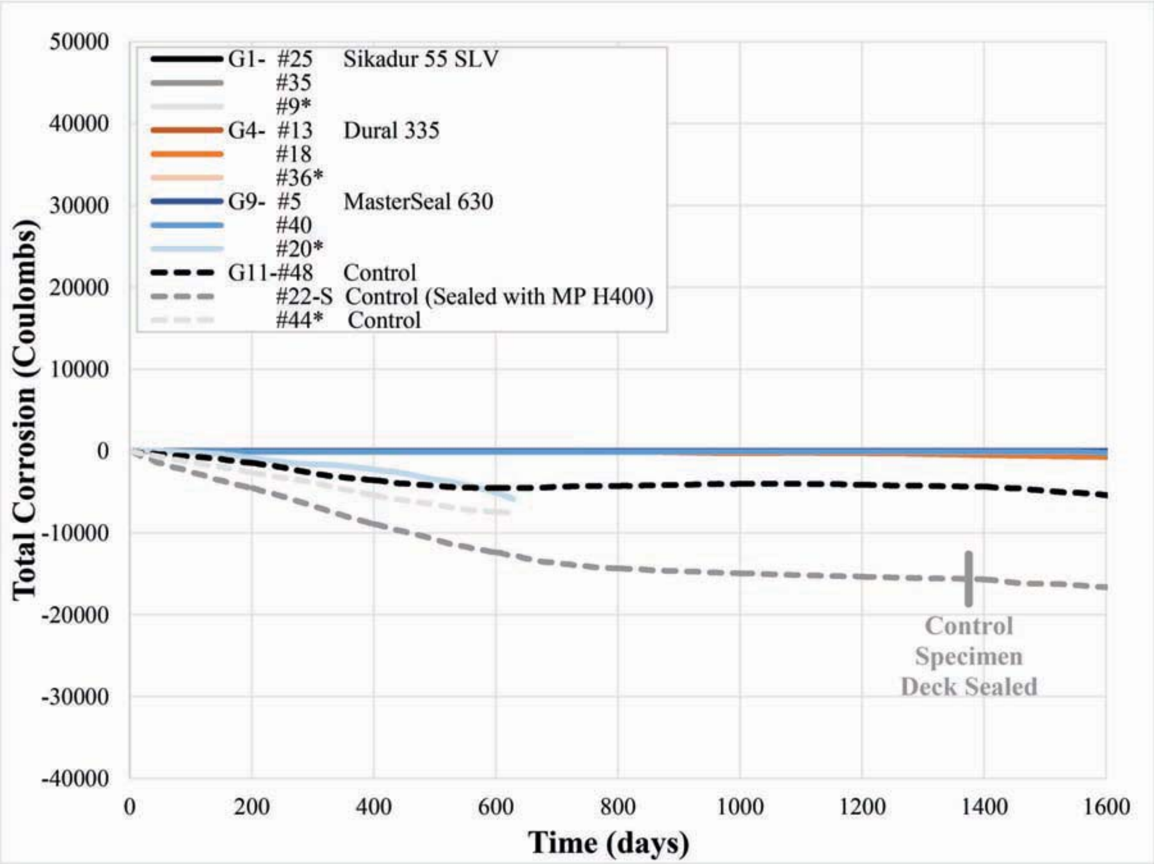


Figure 4.8 Crack sealers—electrical activity history.

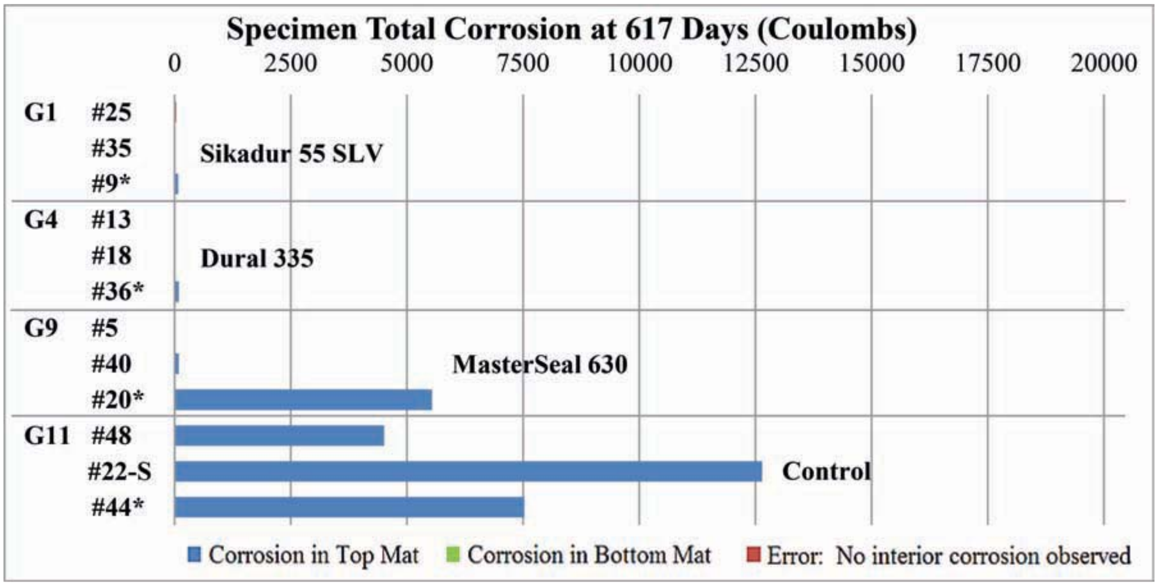


Figure 4.9 Crack sealers—electrical activity at 617 days.

flow of electrons between the two mats of reinforcement causes corrosion at an anode in the top mat. Conversely, positive values, such as in Specimen No. 3, indicate a reversal in the flow of current, which instead drives corrosion in the bottom mat. The magnitude of total corrosion values at 617 days in Figure 4.16 show that the deck sealer specimens were already exhibiting corrosion activity similar to that of the unsealed control specimens. At 1600 days, corrosion of the specimens with deck sealers remained comparable to and even exceeded in

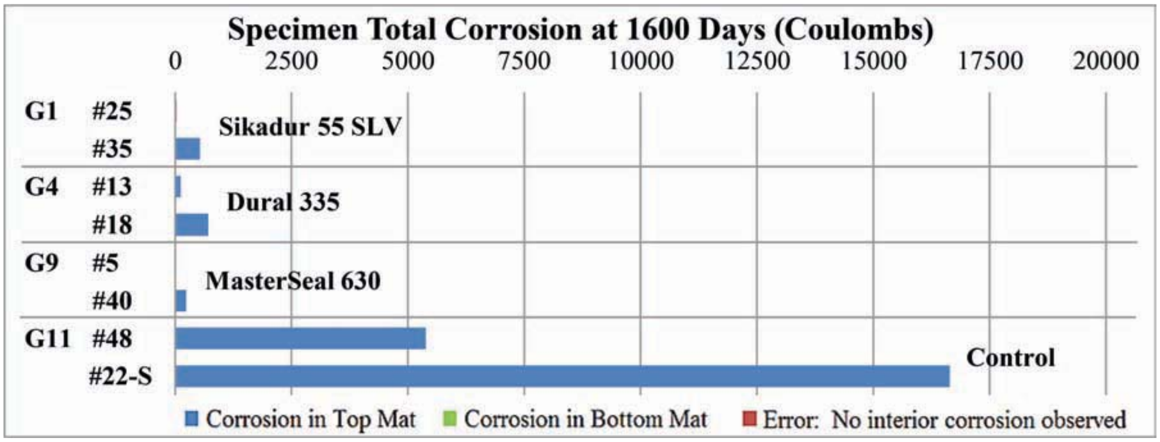


Figure 4.10 Crack sealers—electrical activity at 1600 days.

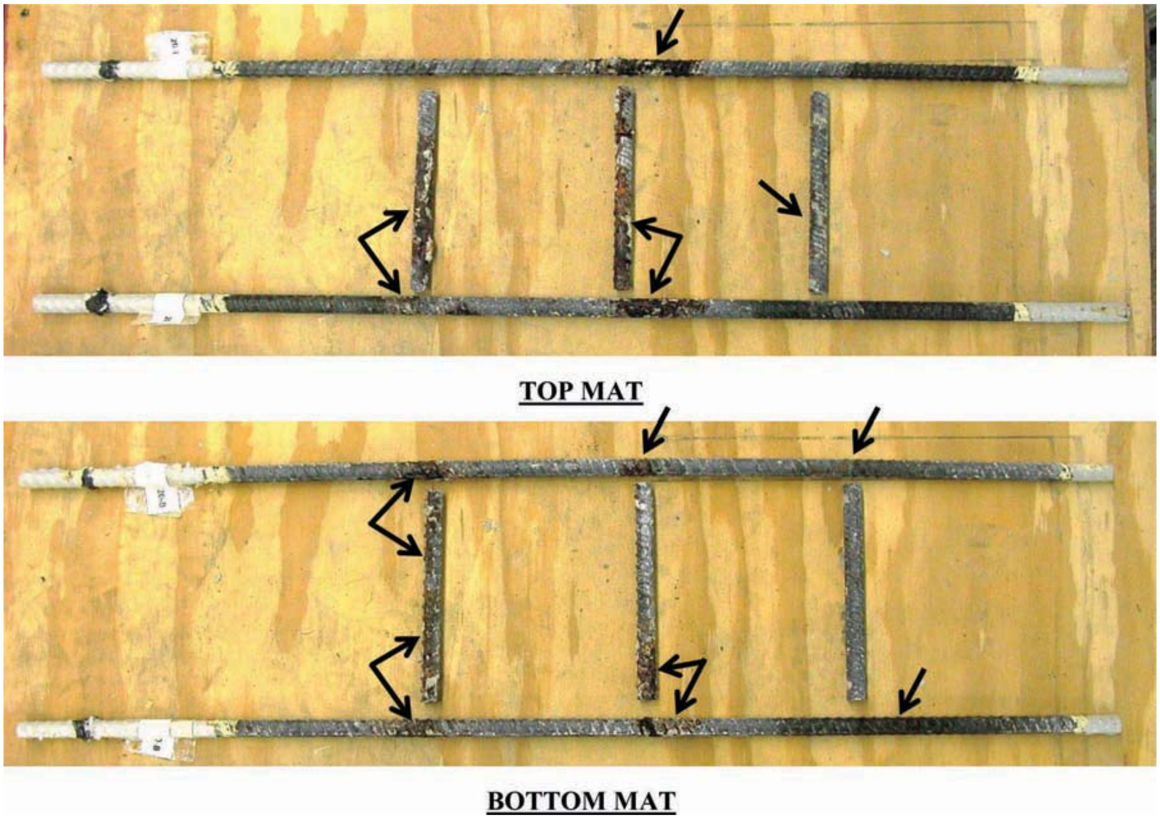


Figure 4.11 Top and bottom mats of MasterSeal 630 Specimen No. 20.

some cases that of the unsealed control specimens, as shown in Figure 4.17.

During autopsy, it was noted that the interiors of each of the deck sealer specimens were either damp or held standing water in the large pores of the concrete. For example, the removal of the longitudinal bars from Specimen No. 42 in Group 5 revealed the darkened, damp concrete interface shown in Figure 4.18. This cracked specimen had been sealed with MasterProtect H 400 and was found to be damp inside despite the fact that the last cycle of salt water had been removed from its surface 45 days prior to the autopsy. It appears that the deck sealer also prevented moisture loss from the interior of the specimen.

The sums of the ratings assigned to each specimen during autopsy using the two rating methods are presented in Figure 4.19 and Figure 4.20. The observed amount of deck sealer specimen corrosion was less than or equal to the corrosion of the two controls. Overall, the deck sealer performance was rated to be similar to that of control specimen No. 48. However, unlike in the electrical measurements, all the deck sealer autopsy ratings were under half that of control Specimen No. 22.

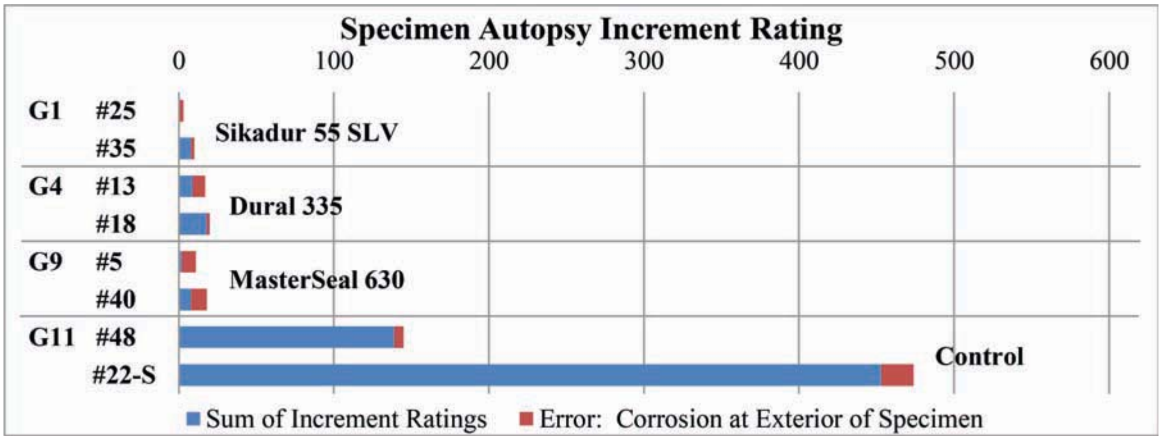


Figure 4.12 Crack sealers—Specimen Autopsy Increment Rating.

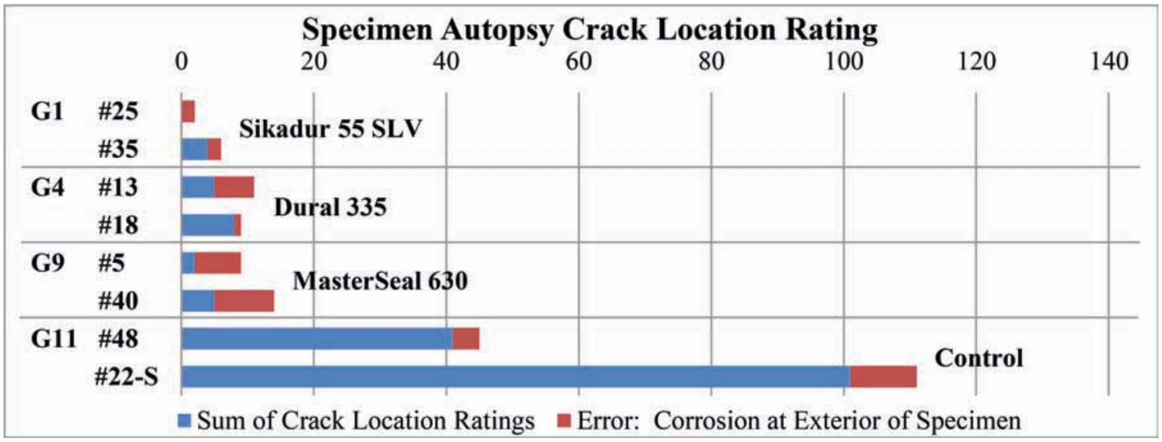


Figure 4.13 Crack sealers—Specimen Autopsy Crack Location Rating.

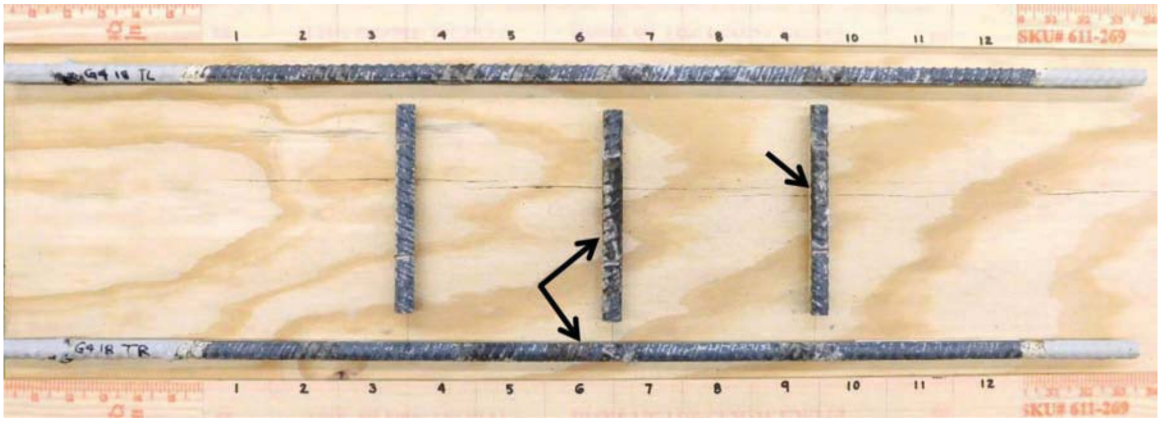


Figure 4.14 Corrosion of top mat of Specimen No. 18.

The electrical measurements and autopsy results showed that the use of deck sealers may result in corrosion levels similar to or even exceeding that of an unsealed deck. The moisture observed in the deck specimens indicates that the sealers do not prevent water intrusion at cracks, as corrosion in these specimens was observed to occur specifically at crack locations. An example of the corrosion observed at crack locations is shown in Figure 4.21. Furthermore, it is possible that the deck sealers may actually inhibit the moisture in the deck from evaporating, thus encouraging even more corrosion than in an unsealed deck. Overall, it was seen that deck sealers are ineffective at preventing salt water intrusion and reducing corrosion in cracked concrete. It should be noted here that the applied deck sealers were only surface applied. There was not intentional effort to flood the cracks with these products.

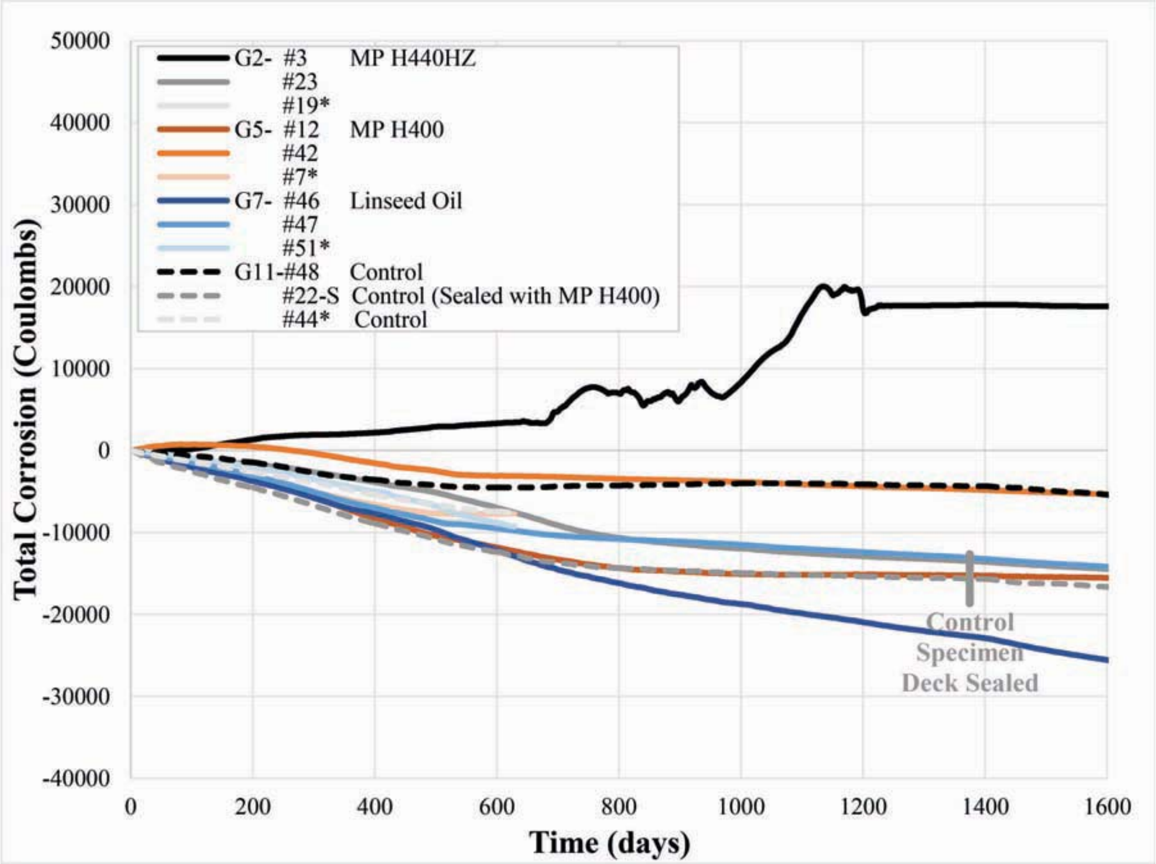


Figure 4.15 Deck sealers—electrical activity history.

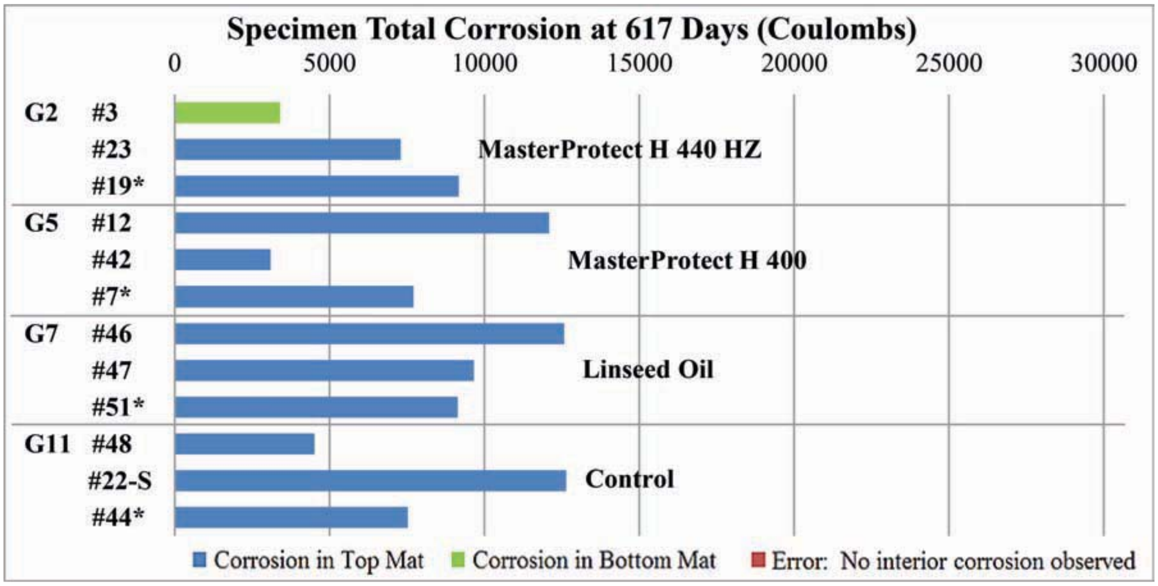


Figure 4.16 Deck sealers—electrical activity at 617 days.

4.3.3 Crack and Deck Sealer Combinations

Various combinations of crack and deck sealers were applied to the specimens in Groups 3, 6, 8, and 10. The electrical measurements recorded over time for these specimens and the control specimens of Group 11 are shown in Figure 4.22, while the measurements taken at 617 days and 1600 days are shown in Figure 4.23 and Figure 4.24. The sealer combinations produced varying results, which were further examined by comparing the results of visible corrosion ratings during the 2016 autopsy, as presented in Figure 4.25 and

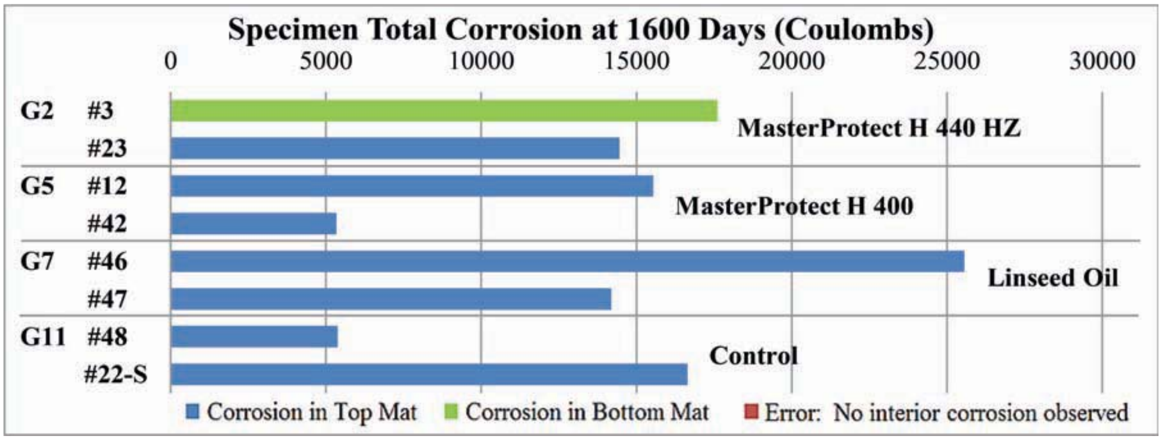


Figure 4.17 Deck sealers—electrical activity at 1600 days.

Figure 4.18 Specimen No. 42—damp interior of deck sealer specimen.

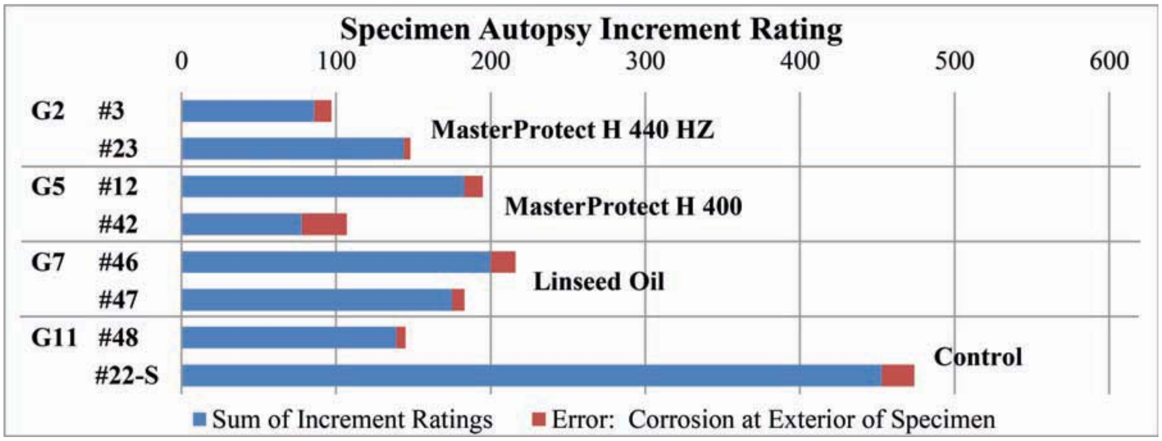


Figure 4.19 Deck sealers—Autopsy Increment Rating.

Figure 4.26. The subsequent sections examine the correlations and disparities between the recorded electrical activity and autopsy ratings for each crack and deck sealer combination.

4.3.3.1 Sikadur 55 SLV and MasterProtect H 440 HZ (Group 3). Sikadur 55 SLV and MasterProtect H 440 HZ proved to be an effective sealer combination. As seen in Figure 4.23, there was no electrical activity

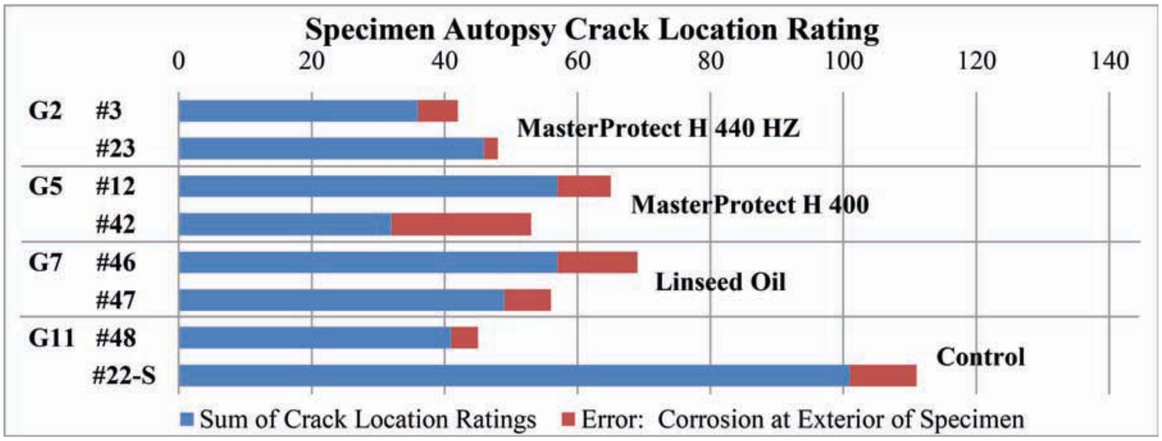


Figure 4.20 Deck sealers—Autopsy Crack Location Rating.

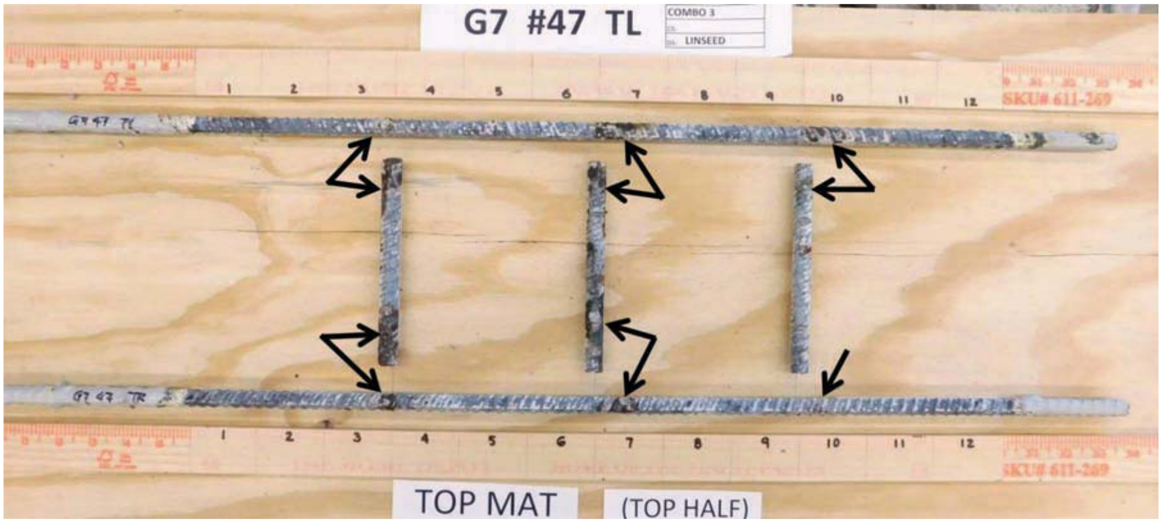


Figure 4.21 Corrosion at crack locations in deck sealer Specimen No. 47.

recorded for Group 3 at 617 days. The autopsy at 1600 days revealed no observable corrosion within the specimens, as seen in Figure 4.25 and Figure 4.26. The corrosion observed occurred only on the portions of the longitudinal bars protruding from the concrete, not at crack locations. As a result, any electrical activity measured at 1600 days in Figure 4.24 is shown in red as erroneous data because the electrical current flow can be attributed to corrosion occurring only in areas outside the specimen.

4.3.3.2 Dural 335 and MasterProtect H 400 (Group 6). The three specimens in Group 6 sealed with Dural 335 and MasterProtect H 400 exhibited low to moderate electrical activity at 617 days, as shown in Figure 4.23. Specimen No. 14 exhibited the most electrical activity, which matched the corrosion observed during the preliminary autopsy of 2013. The autopsy revealed corrosion activity primarily at the first crack, at the location of the front transverse bar in the top mat, as shown in Figure 4.27 and Figure 4.28.

The other two specimens treated with Dural 335 and MasterProtect H 400 remained in service until their autopsy in 2016. Their electrical activity history shown in shades of orange in Figure 4.22 suggests some light corrosion may have occurred in Specimen No. 16, while the high positive value of total corrosion in Specimen No. 49 suggests corrosion occurred on its bottom bars. The autopsy of Specimen No. 49 revealed corrosion that had initiated on the exposed end of the bottom left longitudinal bar and extended as far as 3 in. into the concrete (Figure 4.29). Specimen No. 16 did not exhibit corrosion within the specimen, but the exposed steel had experienced some corrosion. Given the results of these two autopsies, the total corrosion at 1600 days for Group 6 is shown in red in Figure 4.24 to indicate that the recorded electrical measurements were not caused by deficiencies of the sealer.

Although the electrical measurements for this group indicated poor performance, the autopsy results were used to determine that the use of Dural 335 and MasterProtect H 400 can be an effective sealer combination. The

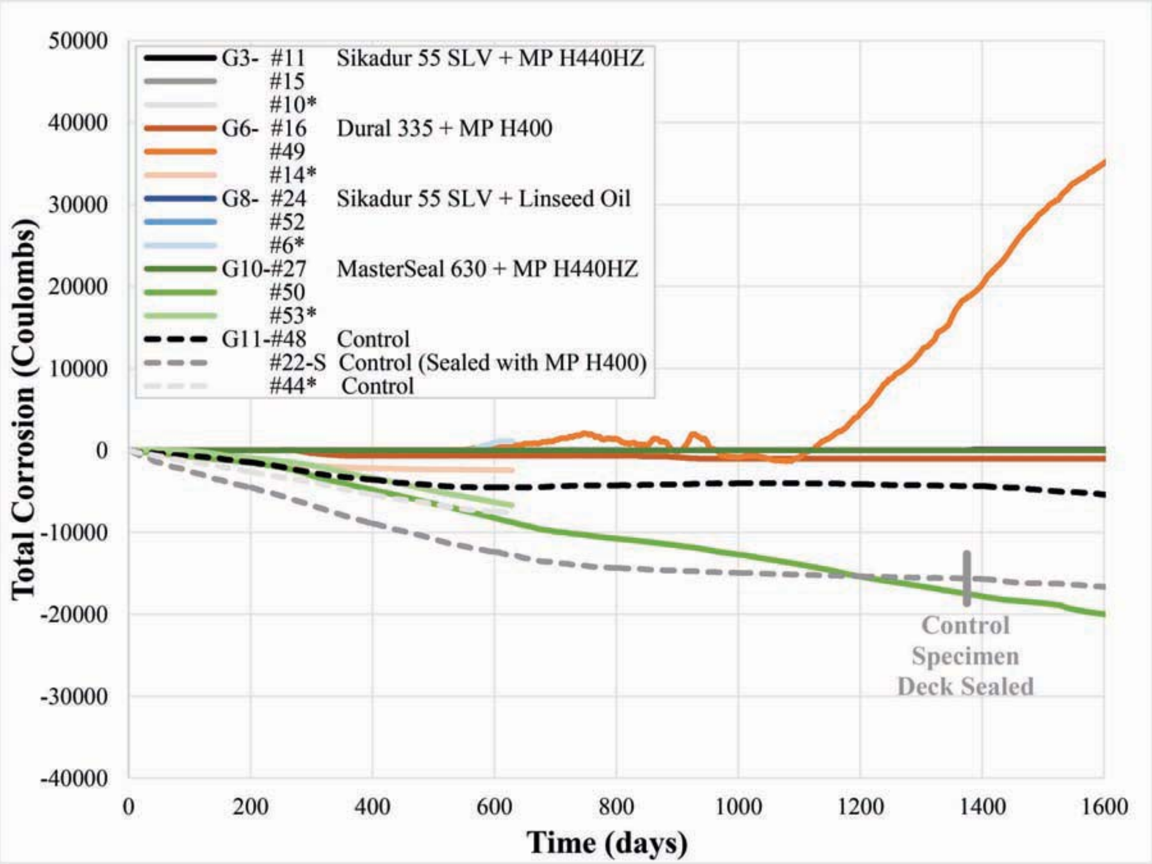


Figure 4.22 Sealer combinations—electrical activity history.

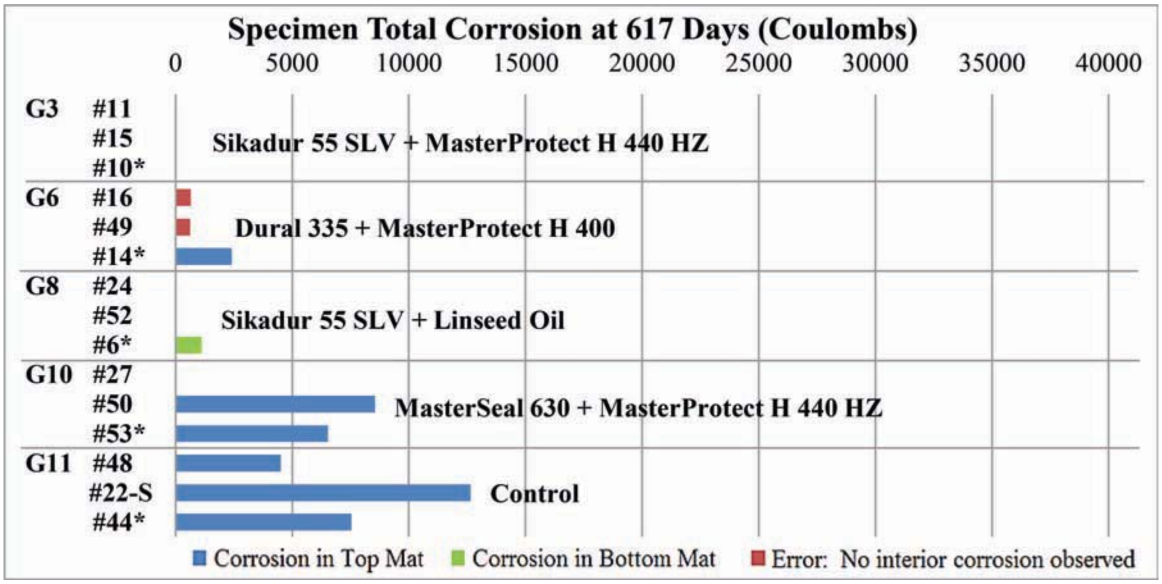


Figure 4.23 Sealer combinations—electrical activity at 617 days.

only corrosion observed was located at one crack in Specimen No. 14 during the 2013 preliminary autopsy. Overall, this combination was successful in reducing corrosion and performed nearly as well as the combination of Sikadur 55 SLV and MasterProtect H 440 HZ.

4.3.3.3 Sikadur 55 SLV and Linseed Oil (Group 8). The combination of Sikadur 55 SLV and linseed oil was also seen to be effective in reducing corrosion. At 617 days, only Specimen No. 6 in Group 8 exhibited electrical activity (Figure 4.23). During the preliminary

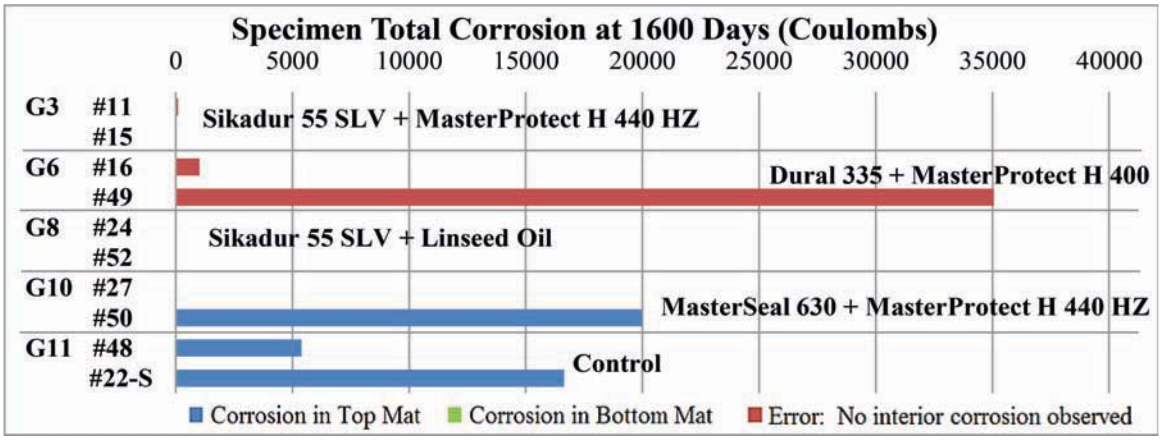


Figure 4.24 Sealer combinations—electrical activity at 1600 days.

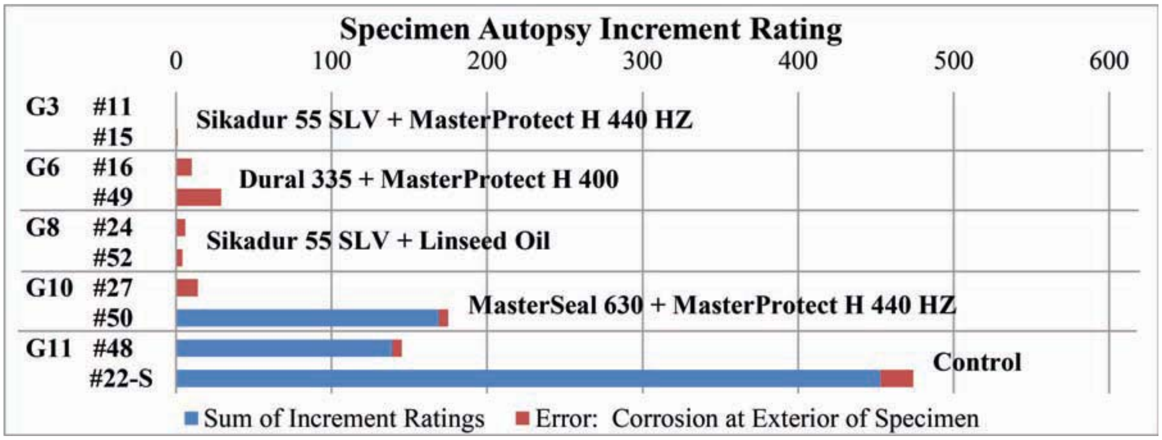


Figure 4.25 Sealer combinations—Autopsy Increment Rating.

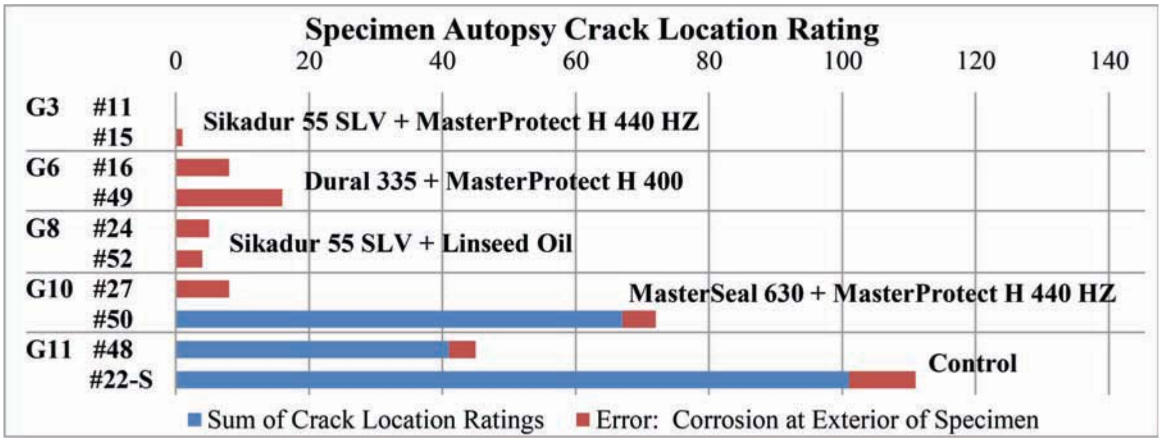


Figure 4.26 Sealer combinations—Autopsy Crack Location Rating.

autopsy of 2013, Specimen No. 6 was found to have some small areas of corrosion, primarily on the front transverse bar of the top mat, as shown in Figure 4.30.

As shown in Figure 4.25 and Figure 4.26, the two specimens from Group 8 autopsied after 1600 days did not show any interior corrosion. Only minimal corrosion (recorded in red) was observed at the protruding ends of the longitudinal bars. In addition, there was no electrical activity recorded for Group 8 at 1600 days (Figure 4.24).

The electrical activity and autopsy results supported Sikadur 55 SLV and linseed oil as an effective sealer combination. Only some light corrosion was identified on Specimen No. 6 prior to autopsy in 2013. The combination Sikadur 55 SLV and linseed oil exhibited

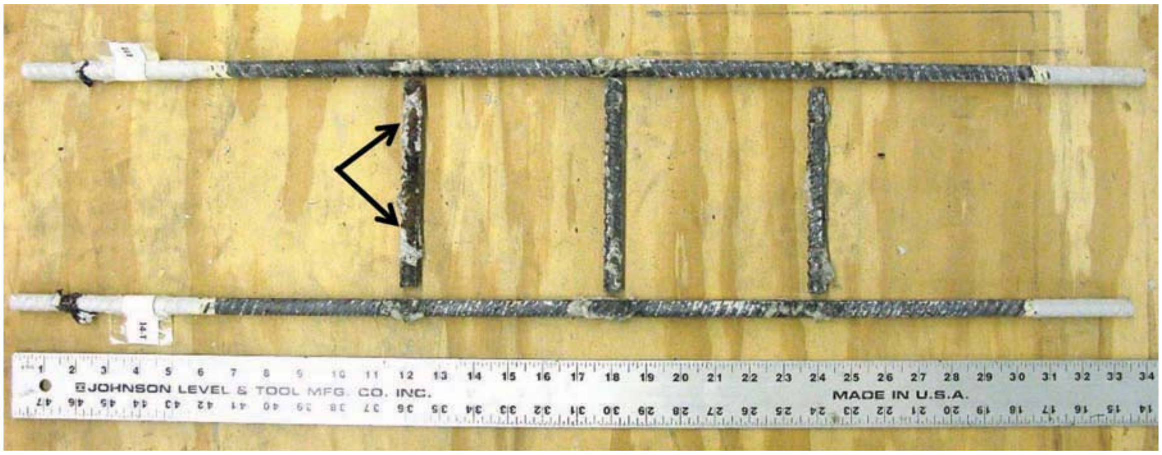


Figure 4.27 Specimen No. 14—top mat corrosion.

Figure 4.28 Specimen No. 14—close-up of front top transverse bar.

Figure 4.29 Specimen No. 49—corrosion on bottom left longitudinal bar.

performance similar to that of the combination of Sikadur 55 SLV and MasterProtect H 440 HZ.

4.3.3.4 MasterSeal 630 and MasterProtect H 440 HZ (Group 10). The combination of MasterSeal 630 and MasterProtect H 440 HZ produced corrosion in two of the three specimens, as noted in the electrical measurements taken at 617 days (Figure 4.23). Specimen No. 53 was autopsied in 2013 to reveal some light corrosion at the first crack in the top mat and severe corrosion at the third crack in both the top and bottom mats, as shown in Figure 4.31. This severe corrosion corresponds to the electrical reading at 617 days with similar magnitude to that of the control specimens.

The remaining specimens, No. 27 and No. 50, recorded contrasting electrical measurements at 1600 days.

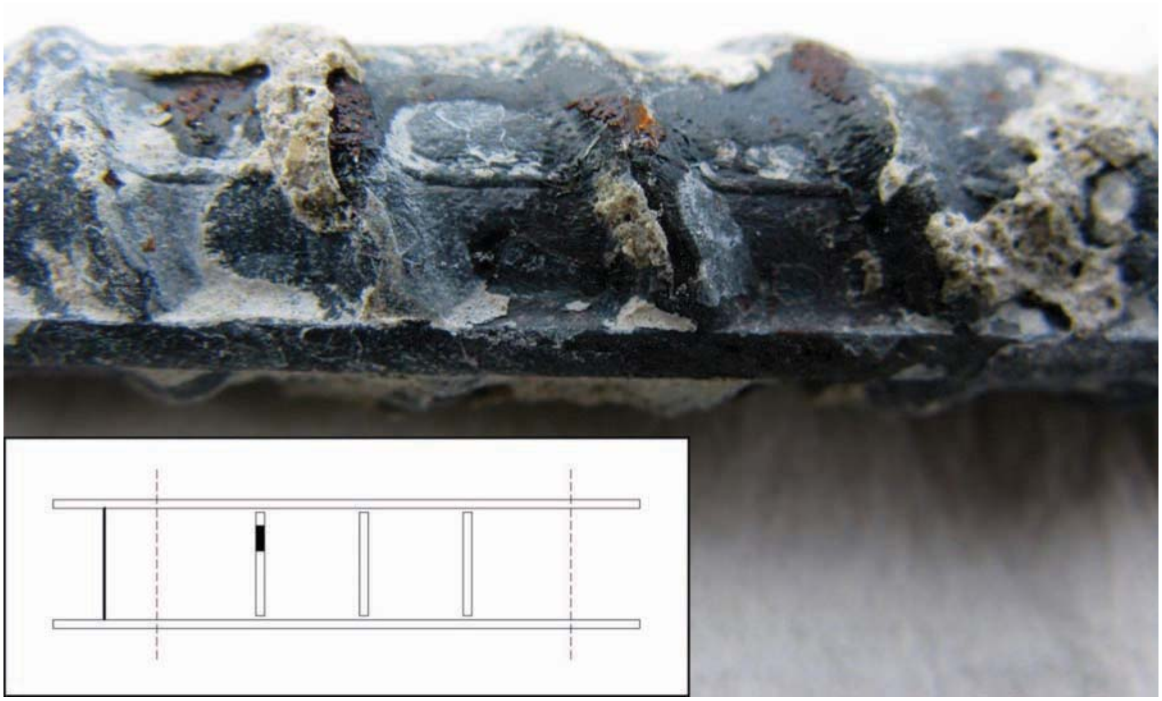


Figure 4.30 Specimen No. 6—close-up of front top transverse bar.

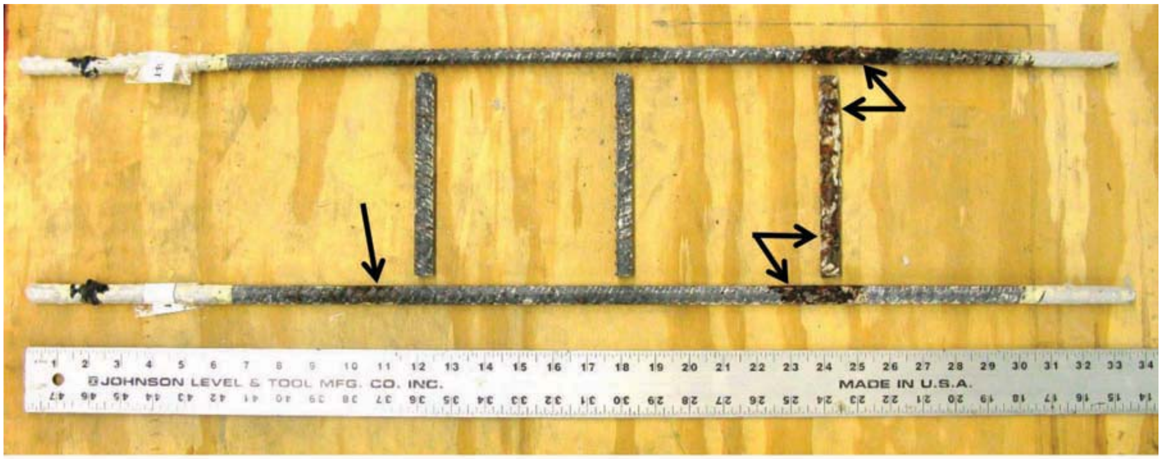
No. 27 recorded negligible electrical activity, while No. 50 showed electrical activity greater than that of all the control specimens. During autopsy after 1600 days, Specimen No. 27 showed no interior corrosion. Conversely, Specimen No. 50 provided clear indication of corrosion prior to autopsy. Corrosion product could be seen seeping to the surface of the specimen at the location of the second of four cracks, located halfway between the first and second transverse bars, as shown in Figure 4.32. Upon autopsy, severe corrosion was seen at the second crack, as well as moderate corrosion at the first and third cracks (Figure 4.33). No corrosion was observed at the fourth crack. The corrosion of the reinforcement in the top and bottom mats of Specimen No. 50 is shown in Figure 4.34.

The second crack appears to have been the corrosion initiation point for Specimen No. 50, which renders skepticism of the effectiveness of the MasterSeal 630 product. It is possible that the second crack was not entirely filled with the crack sealer. Additionally, although the cracks were sealed with silicone at the sides and bottom of the specimen to prevent the product from draining, it is possible that this sealer, being a methacrylate of even lower viscosity than the two epoxy crack sealers, may have leaked out of the specimen during application. As discussed previously, MasterSeal 630 had a similar localized failure in the crack sealer comparison (Section 4.3.1) when it effectively sealed two of the three specimens and only sealed one of the three cracks in the third specimen, No. 20 (Figure 4.11). Both the crack sealer comparison and the sealer combination comparison suggest that that the methacrylate crack sealer, MasterSeal 630, may be more sensitive to installation than the epoxy sealers Sikadur 55 SLV and Dural 335 especially for these crack widths. Overall, the sealer combination of MasterSeal 630 and MasterProtect H 440 HZ had mixed success in reducing corrosion.

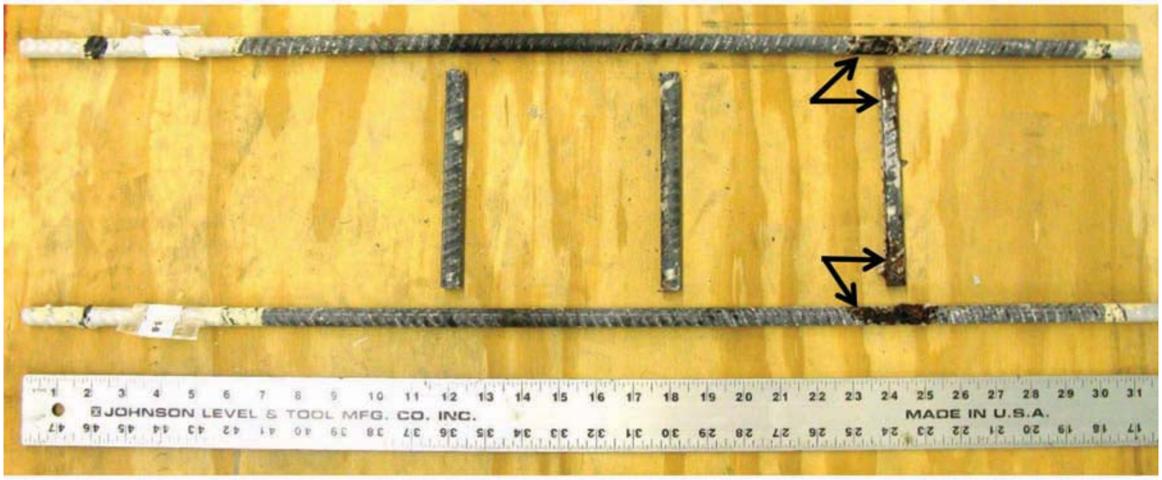
4.3.4 Restressing

In general, all the cracked specimens were restressed to 2/3 of yield stress after sealer application to simulate stresses induced in a typical bridge deck due to concrete shrinkage, thermal movement, and traffic loading. Groups 12 and 13 were not restressed in order to examine the difference in sealer performance due to restressing. Group 12 consisted of specimens treated with only the crack sealer Sikadur 55 SLV, while the combination of Sikadur 55 SLV and MasterProtect H 440 HZ was applied to Group 13.

4.3.4.1 Sikadur 55 SLV. The electrical activity over time for Group 12 is compared with the restressed Sikadur 55 SLV specimens of Group 1 and the control Group 11 in Figure 4.35. The electrical activity at 617 days (Figure 4.36) indicates the presence of corrosion in unstressed Specimen No. 28; however, the preliminary autopsy in 2013 revealed that the corrosion appeared to have initiated at the exposed steel rather than at a crack location (Figure 4.38). Therefore, the corrosion recorded for Specimen No. 28 is shown in red in Figure 4.36. The other two specimens in Group 12 (No. 1 and No. 26) exhibited negligible corrosion, as seen in the electrical measurements at 1600 days (Figure 4.37). Similarly, the 2016 autopsy ratings presented in Figure 4.39 and Figure 4.40 show slightly more corrosion in the restressed specimens than in the unstressed specimens. It is seen that



TOP MAT



BOTTOM MAT

Figure 4.31 Corrosion in top and bottom mats of Specimen No. 53.

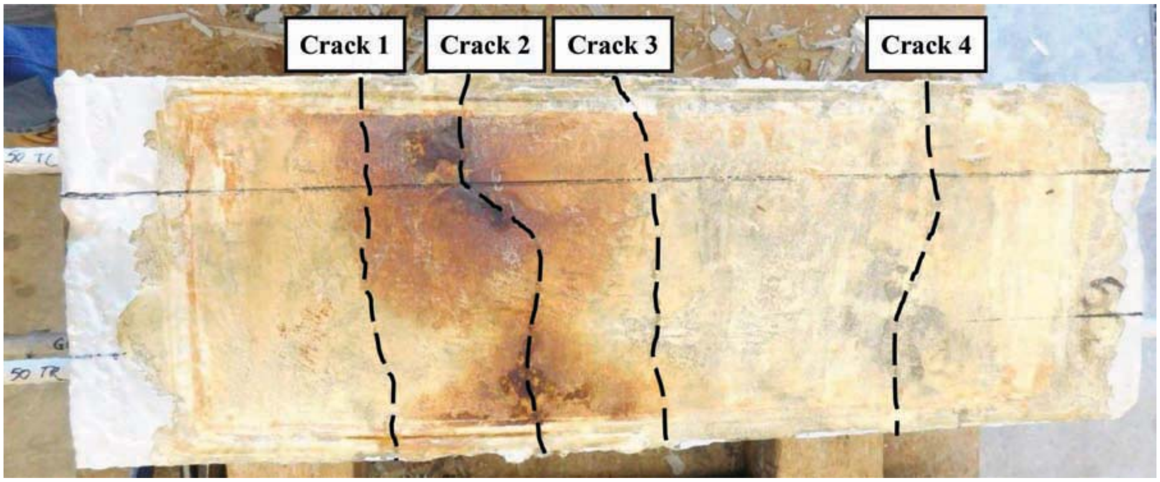


Figure 4.32 Specimen No. 50—surface corrosion staining.

Sikadur 55 SLV is capable of withstanding tensile stressing (up to 40 ksi) while maintaining its ability to effectively reduce corrosion at crack locations.

4.3.4.2 Sikadur 55 SLV and MasterProtect H 440 HZ. The electrical activity history for the unstressed sealer combination in Group 13 is compared to restressed

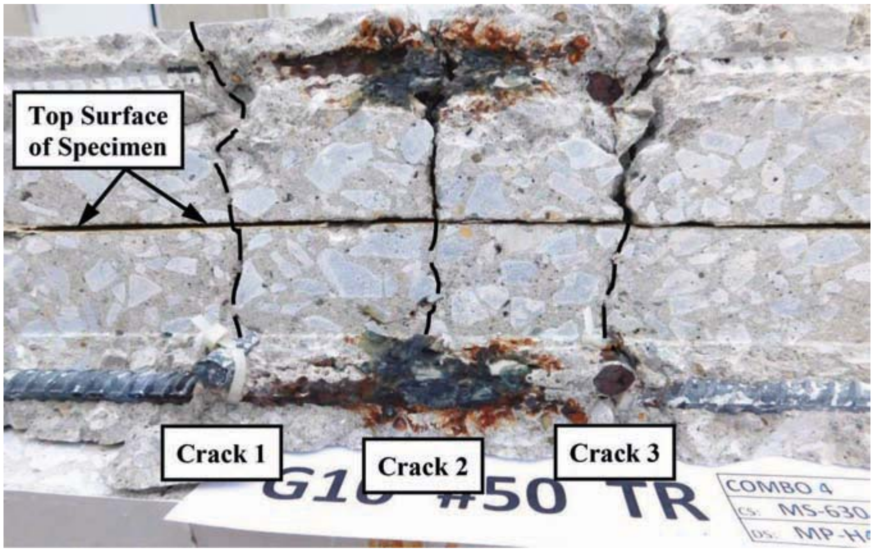
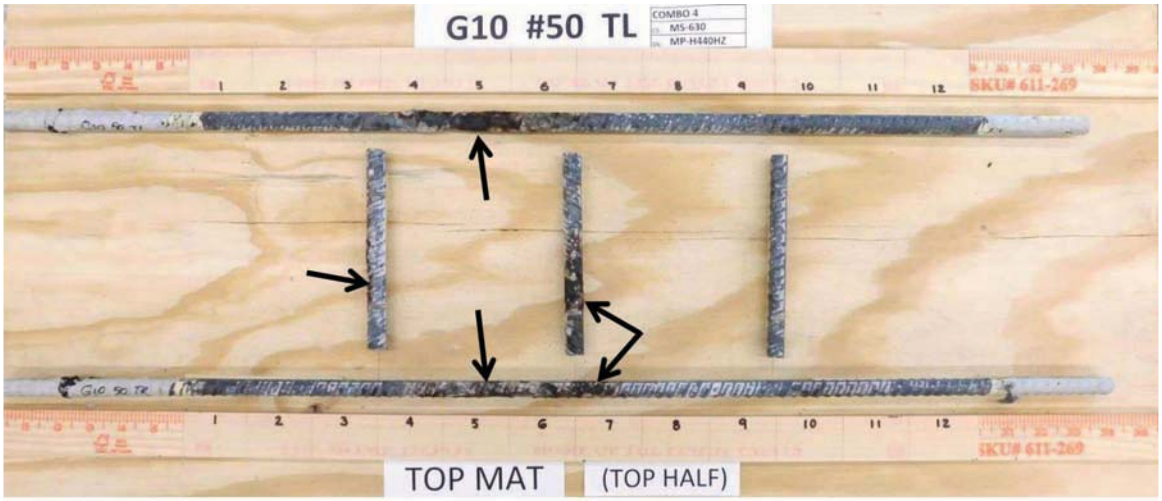
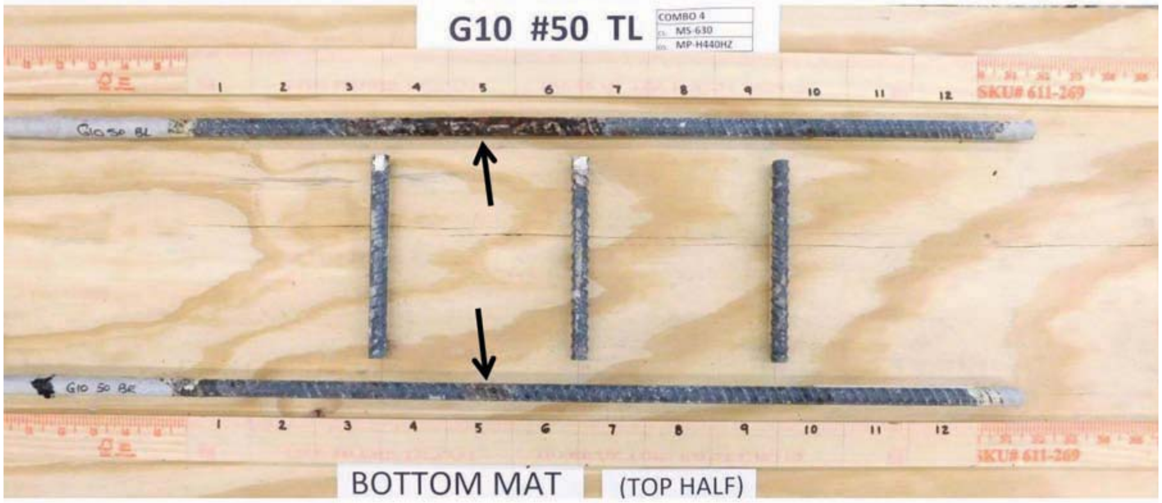


Figure 4.33 Specimen No. 50—corrosion at second crack.



TOP MAT



BOTTOM MAT

Figure 4.34 Corrosion in top and bottom mats of Specimen No. 50.

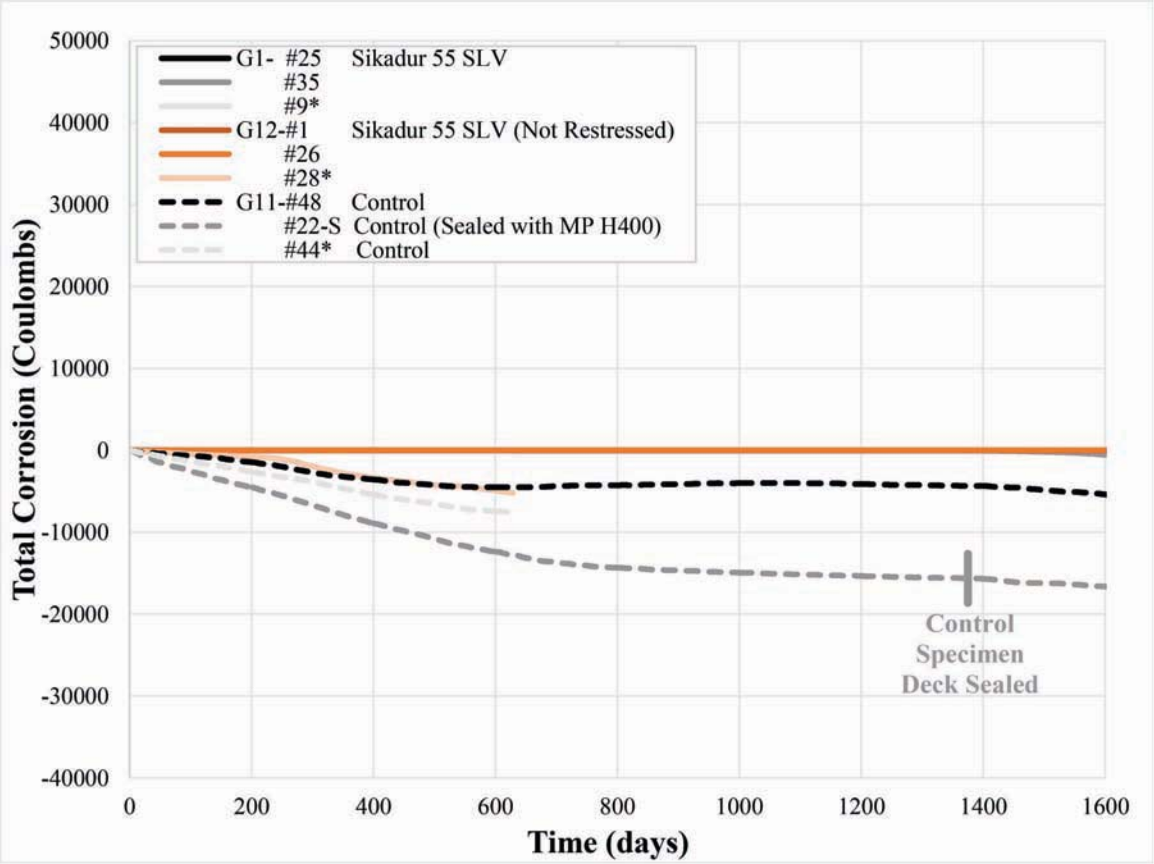


Figure 4.35 Crack sealer restressing—electrical activity history.

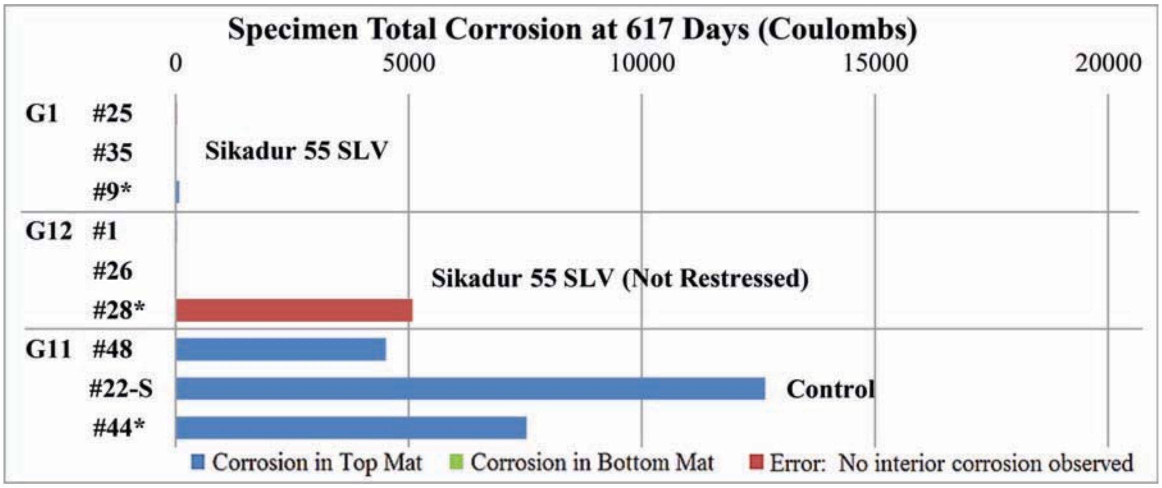


Figure 4.36 Crack sealer restressing—electrical activity at 617 days.

Group 3 and control Group 11 in Figure 4.41. The autopsy results shown in Figure 4.43 and Figure 4.44 indicate that no corrosion occurred in Groups 3 or 13. As such, the negligible amount of electrical activity measured at 1600 days for these groups is shown in red in Figure 4.42. The sealer combination of Sikadur 55 SLV and MasterProtect H 440 HZ is shown to be effective regardless of whether it was restressed.

4.3.5 Crack Sealer Surface Preparation

The manufacturers for crack sealers Dural 335 and MasterSeal 630 recommend surface preparation prior to crack sealing that includes light sandblasting of the entire deck surface followed by cleaning with compressed air, in an effort to give the crack sealer product better access to the cracks. The surfaces of the specimens in Groups 14 and 15 were lightly sandblasted

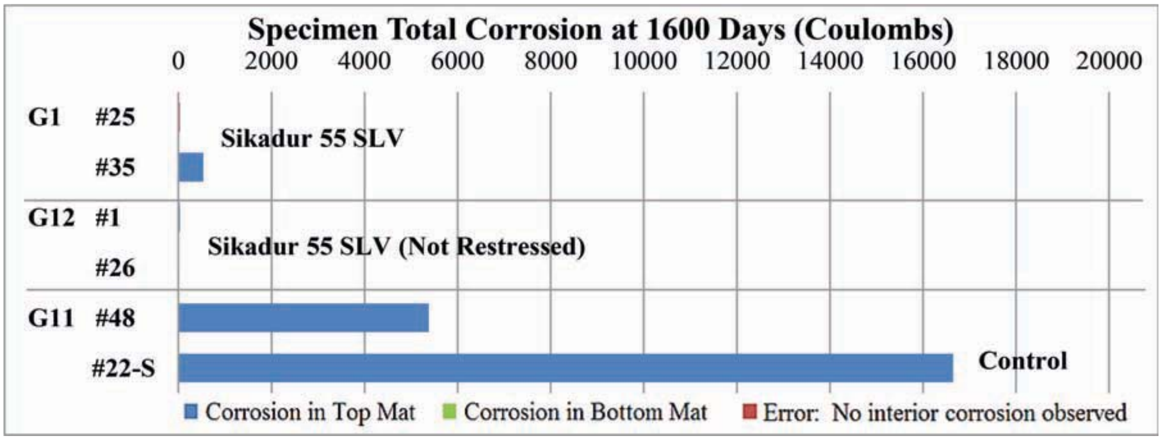


Figure 4.37 Crack sealer restressing—electrical activity at 1600 days.

Figure 4.38 Corrosion in top mat of Specimen No. 28.

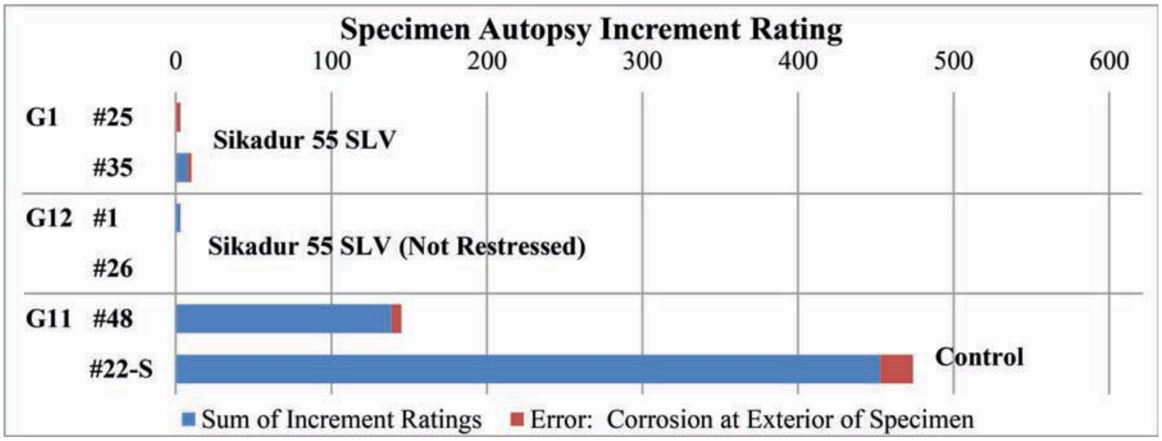


Figure 4.39 Crack sealer restressing—Autopsy Increment Rating.

prior to the application of the crack sealers to investigate the effects of surface preparation on the effectiveness of crack sealers.

4.3.5.1 Dural 335. After lightly sandblasting the surface of each specimen in Group 14, Dural 335 was applied to the cracks. Group 4 was treated with Dural 335 without prior surface preparation. The electrical activity history of Groups 4 and 14 are presented with control Group 11 (no surface preparation) in Figure 4.45.

The electrical measurements at 1600 days shown in Figure 4.46 indicate that one specimen with surface preparation displayed poorer performance than Group 4, while the other displayed better performance. The autopsy results shown in Figure 4.47 and Figure 4.48 reflect the same conflicting outcome. These inconclusive results, paired with labor and equipment costs associated with sandblasting, suggest that surface preparation is not critical to the use of Dural 335. It should be noted that the specimens were cracked and that surface preparation likely had no influence at the crack locations.

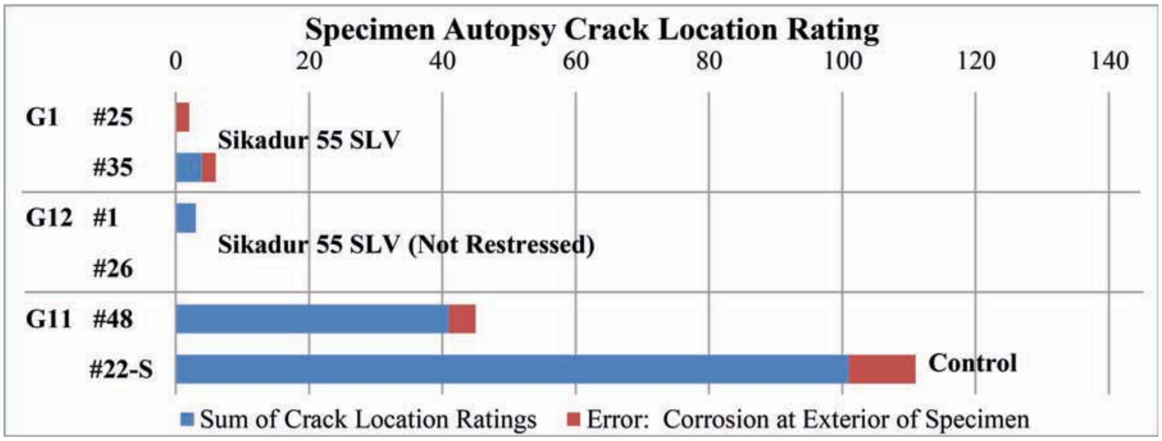


Figure 4.40 Crack sealer restressing—Autopsy Crack Location Rating.

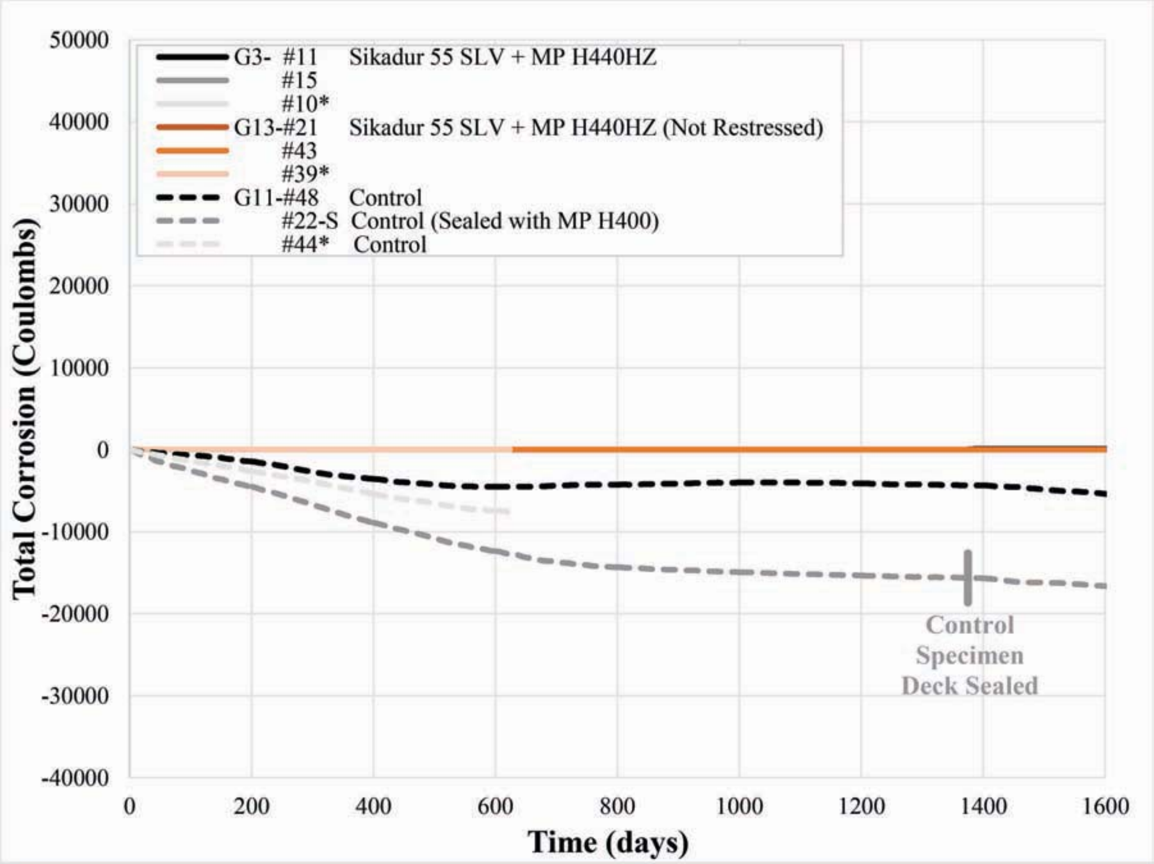


Figure 4.41 Sealer combination restressing—electrical activity history.

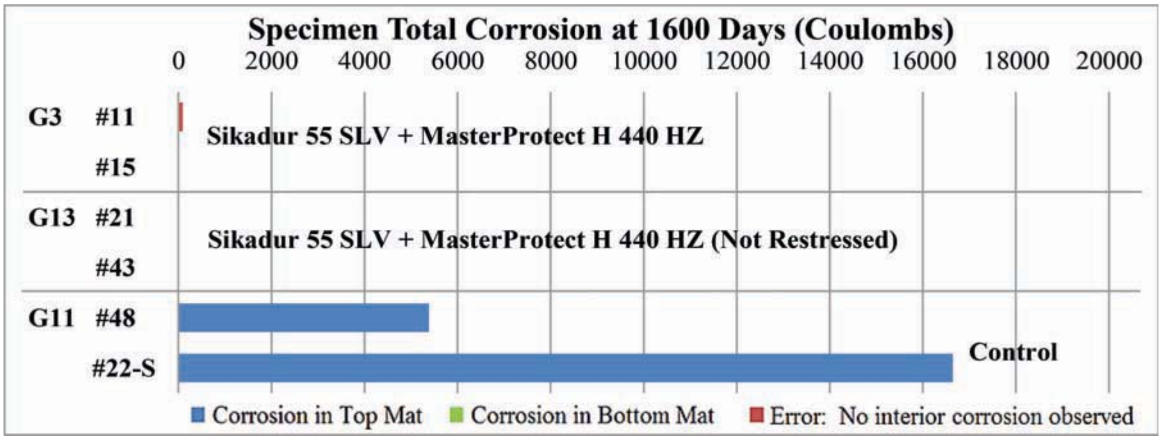


Figure 4.42 Sealer combination restressing—electrical activity at 1600 days.

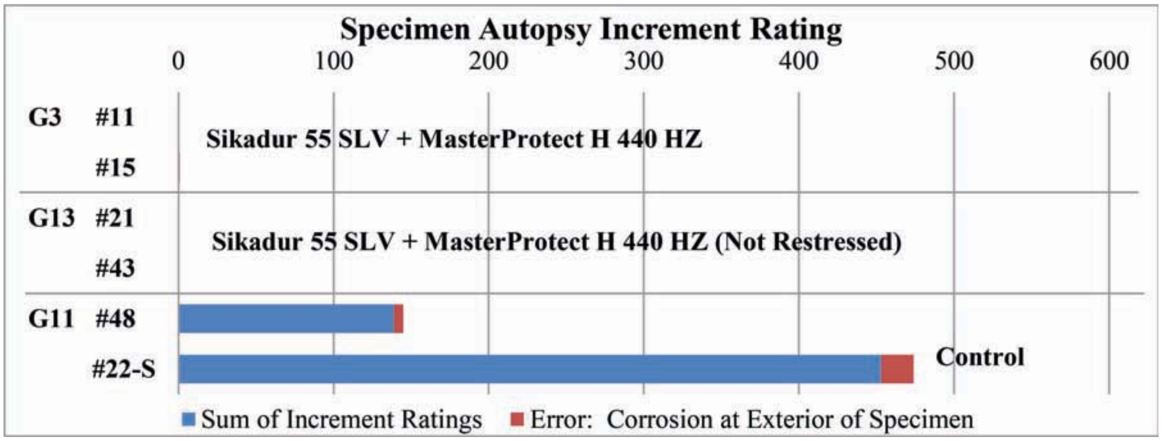


Figure 4.43 Sealer combination restressing—Autopsy Increment Rating.

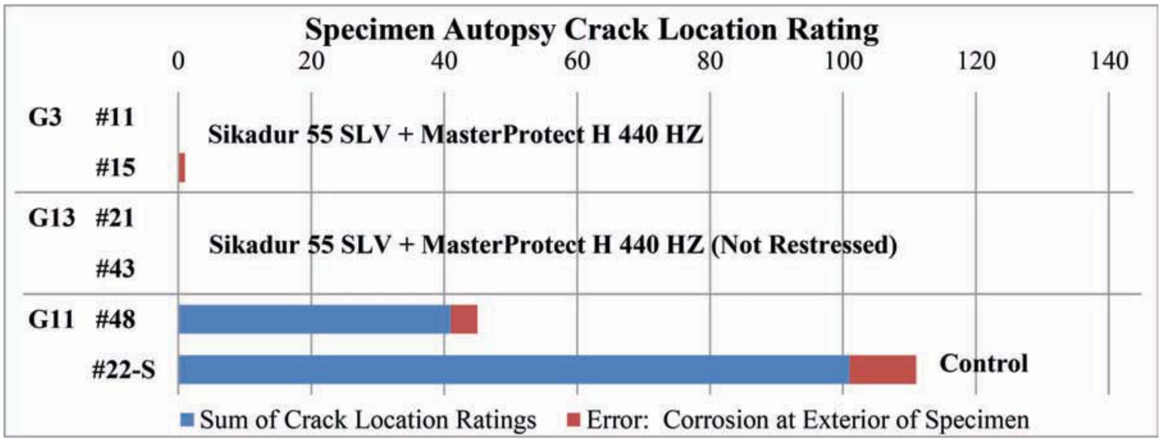


Figure 4.44 Sealer combination restressing—Autopsy Crack Location Rating.

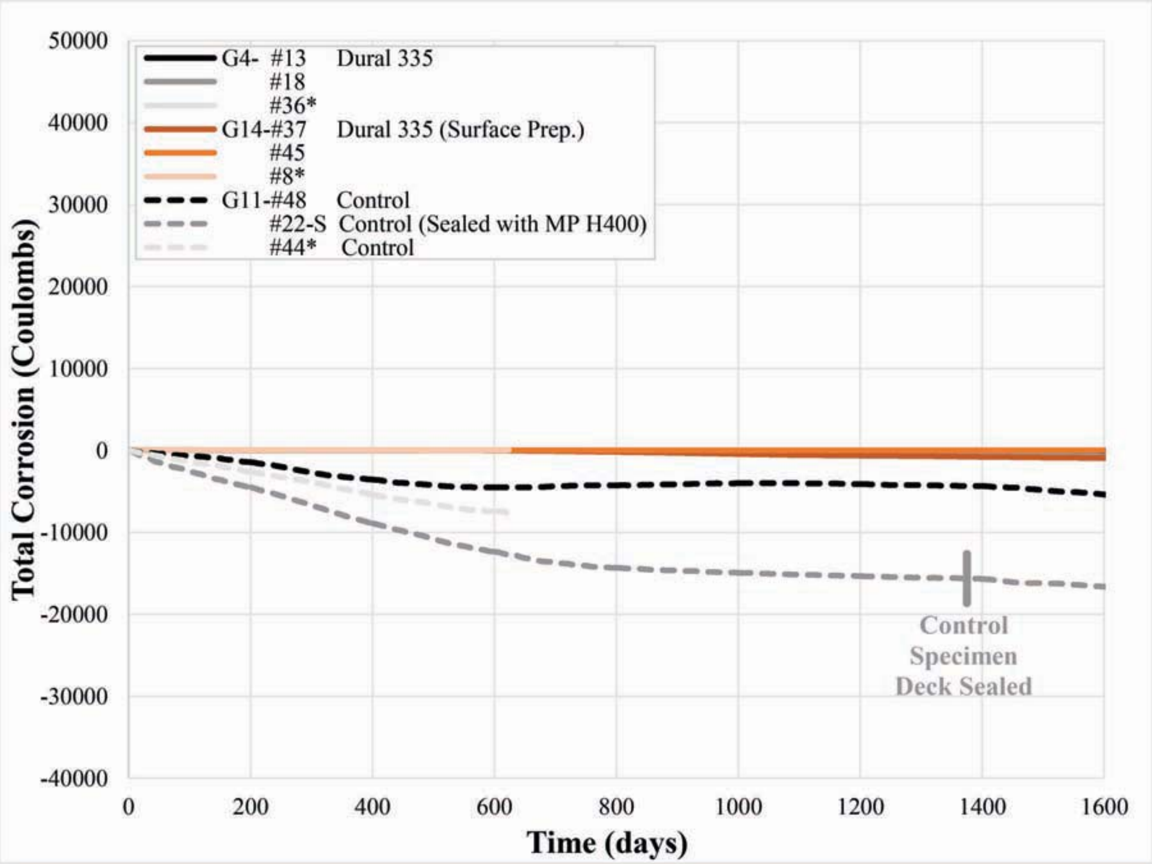


Figure 4.45 Dural 335 surface preparation—electrical activity history.

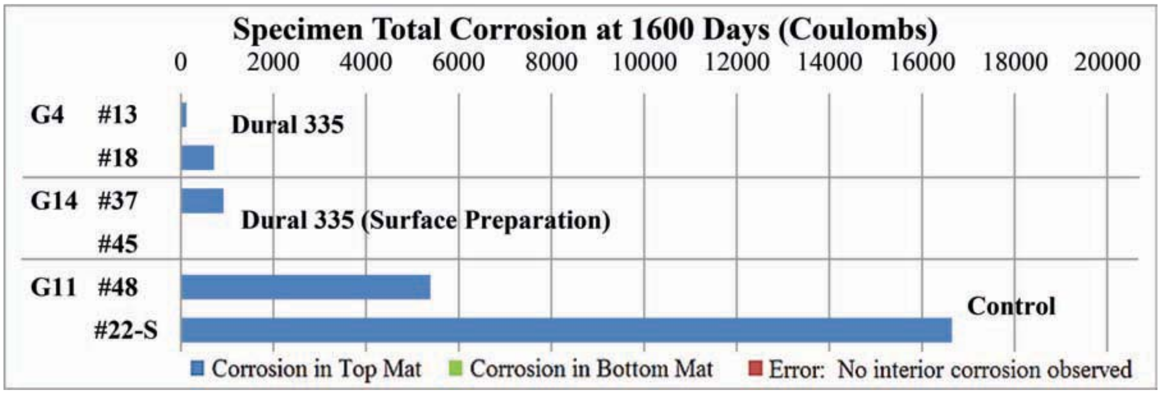


Figure 4.46 Dural 335 surface preparation—electrical activity at 1600 days.

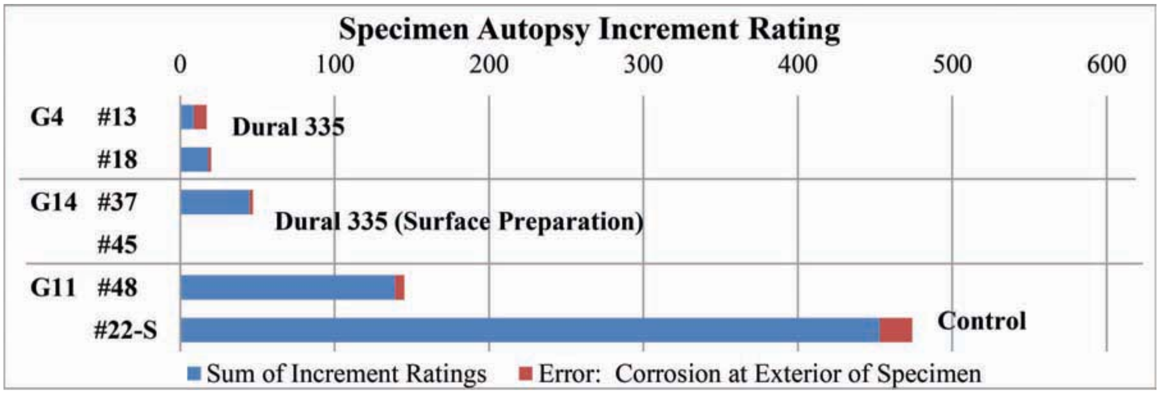


Figure 4.47 Dural 335 surface preparation—Autopsy Increment Rating.

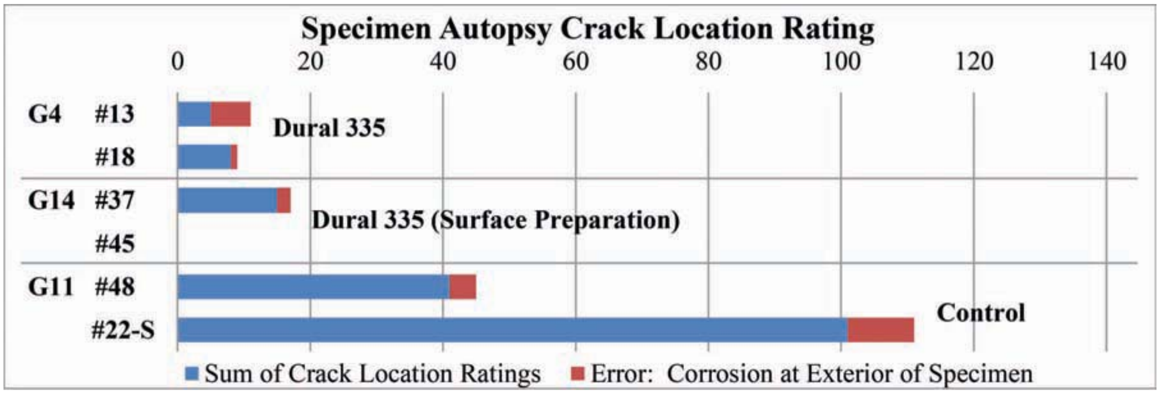


Figure 4.48 Dural 335 surface preparation—Autopsy Crack Location Rating.

4.3.5.2 MasterSeal 630. The effects of surface preparation were also studied for the methacrylate crack sealer MasterSeal 630 using specimen Group 15. The specimens were compared to specimens in Group 9, which were not sandblasted but were also treated with MasterSeal 630. The electrical activity of Groups 9, 15, and control Group 11 over time are shown in Figure 4.49. The intermediate electrical measurements taken at 617 days are presented in Figure 4.50. These measurements show corrosion in one of the three specimens without surface preparation due to failure at crack locations, as discussed in Section 4.3.1, and negligible corrosion in all three of the specimens with surface preparation.

As shown in Figure 4.51, the electrical activity at 1600 days shows no corrosion in Group 15 (surface preparation) and minimal corrosion in one of the two specimens in Group 9 (no surface preparation). Similar results were obtained during autopsies (Figure 4.52 and Figure 4.53). There is no clear benefit from the use of surface preparation prior to crack sealing; therefore, the additional costs of labor and equipment required for sandblasting the deck do not seem to indicate their use for crack sealers.

4.3.6 Epoxy Reinforcement Comparison

Groups 16 and 17 were constructed using epoxy reinforcement instead of black reinforcement. Group 16 was not sealed, while Group 17 was sealed with a combination of Sikadur 55 SLV and MasterProtect H 440 HZ. Figure 4.54 shows the electrical activity recorded over time for Groups 16 and 17. The epoxy coating was damaged using a grinder every 3 in. prior to casting the concrete to represent coating damage that occurs in the field during construction of a bridge deck. The defects in the coating allow chlorides to access the steel to begin the corrosion process. As a result, some corrosion of the epoxy control specimens is expected. Accordingly, some light corrosion occurred in the epoxy control specimens, as shown by the broken green lines in Figure 4.54.

The use of sealers prevented any electrical activity from occurring, even at 1600 days, as shown in Figure 4.55. Similarly, the autopsy results in Figure 4.56 and Figure 4.57 show no interior corrosion on the sealed specimens in Group 17 and mild to moderate corrosion on the epoxy control specimens in Group 16. The use of the sealer combination Sikadur 55 SLV and MasterProtect H 440 HZ in conjunction with epoxy reinforcement results in a deck system that is able to withstand corrosion despite the occurrence of defects in the epoxy coating.

The specimens in Group 17 were investigated further by using a utility knife to evaluate the extent of corrosion extending beneath the coating beyond the locations of visible corrosion. For example, epoxy control specimen No. 33 was autopsied on March 23, 2016.

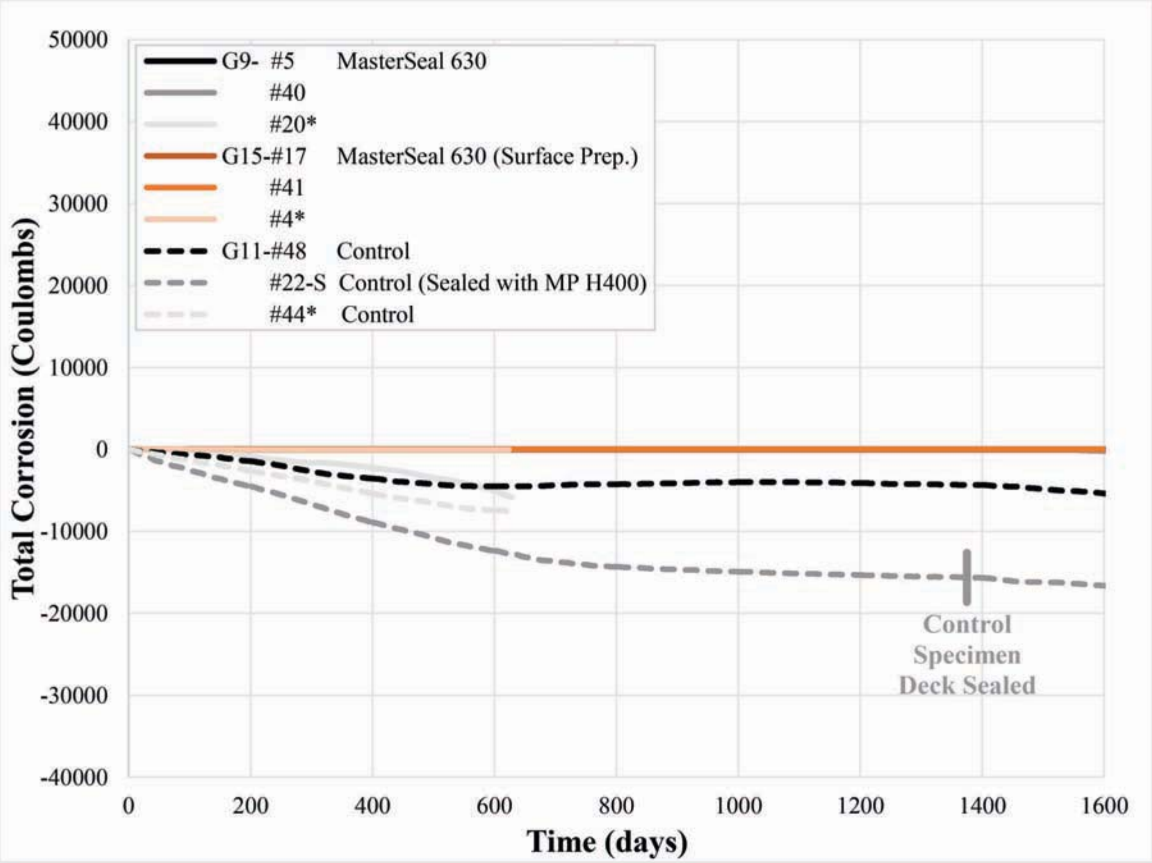


Figure 4.49 MasterSeal 630 surface preparation—electrical activity history.

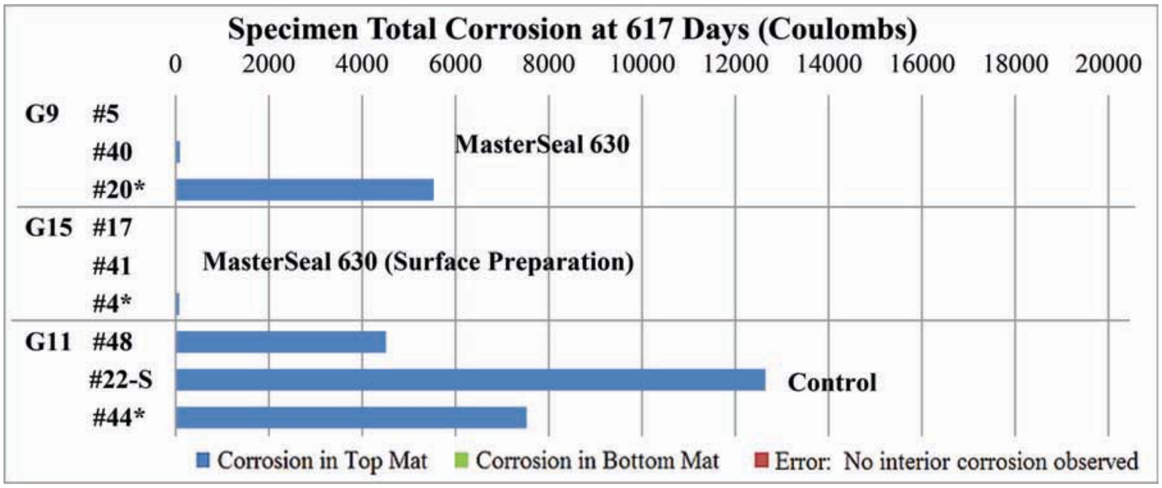


Figure 4.50 MasterSeal 630 surface preparation—electrical activity at 617 days.

Figure 4.58 shows the corrosion visible on the top mat directly after autopsy, with a designated close-up shown in Figure 4.61. After all specimen autopsies were completed, photos were taken again on June 8, 2016, immediately prior to removal of epoxy, to show any additional corrosion that may have occurred while the bars were in storage (Figure 4.59 and Figure 4.62). The removal of epoxy on June 8, 2016 revealed sections of corrosion underneath the adjacent epoxy coating that were over four times the size of what could be seen previously. The top mat after epoxy removal is shown in Figure 4.60, with a close-up photo in Figure 4.63. This investigation showed that the epoxy coating damage that develops in the field can make the reinforcement vulnerable to corrosion in regions much larger than the size of the defect itself.

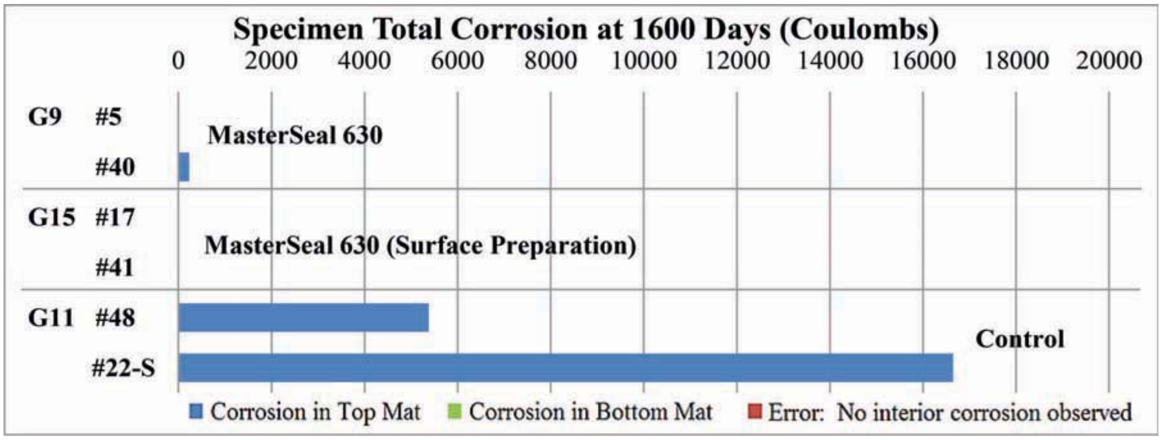


Figure 4.51 MasterSeal 630 surface preparation—electrical activity at 1600 days.

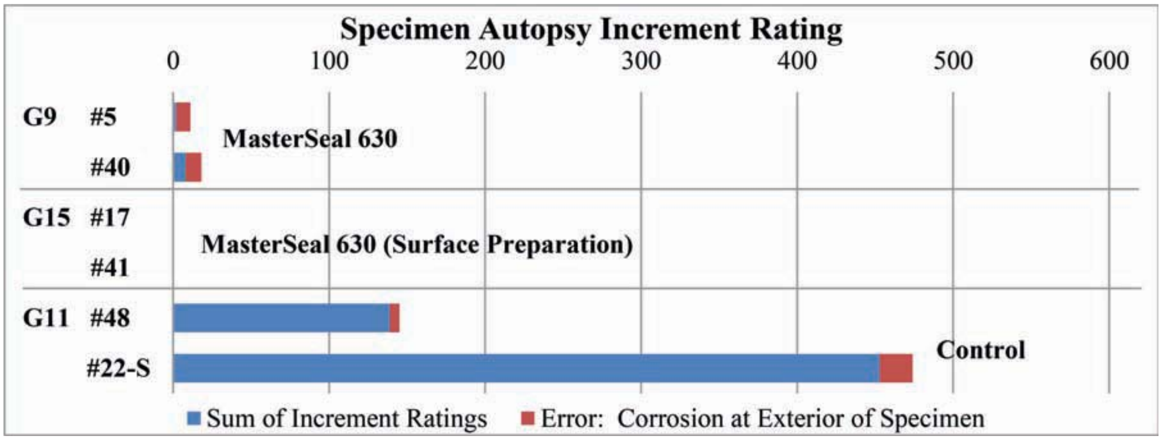


Figure 4.52 MasterSeal 630 surface preparation—Autopsy Increment Rating.

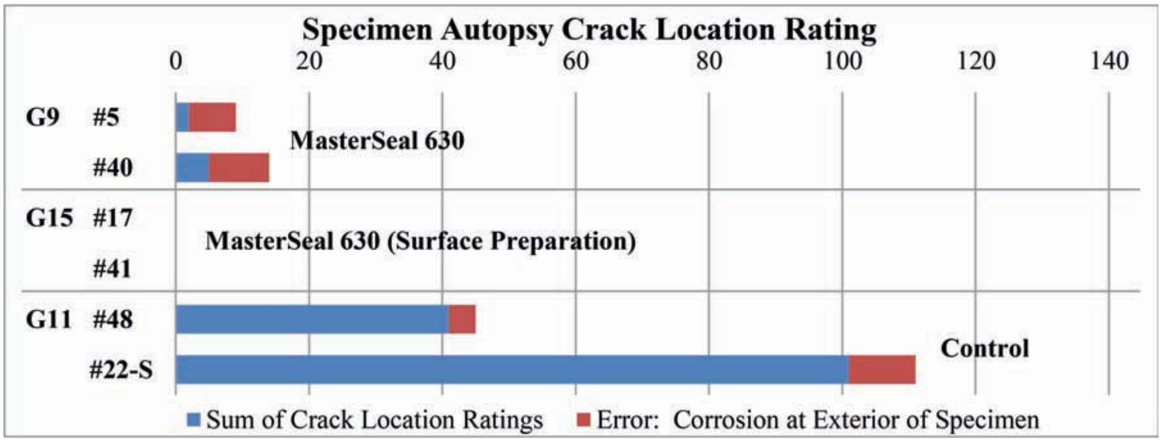


Figure 4.53 MasterSeal 630 surface preparation—Autopsy Crack Location Rating.

4.3.7 Surface Tining Comparison

Groups 18 and 19 were used to examine the effects of surface tining. Group 18 consisted of unsealed control specimens with surface tining, and Group 19 deployed the sealer combination of Sikadur 55 SLV and MasterProtect H 440 HZ on a tined surface. Figure 4.64 displays the electrical activity history for sealed and unsealed groups, both with and without surface tining. The performance of the unsealed Specimen No. 54 with surface tining relative to the untined control (Group 11) demonstrates that a tined surface can cause a deck surface to be

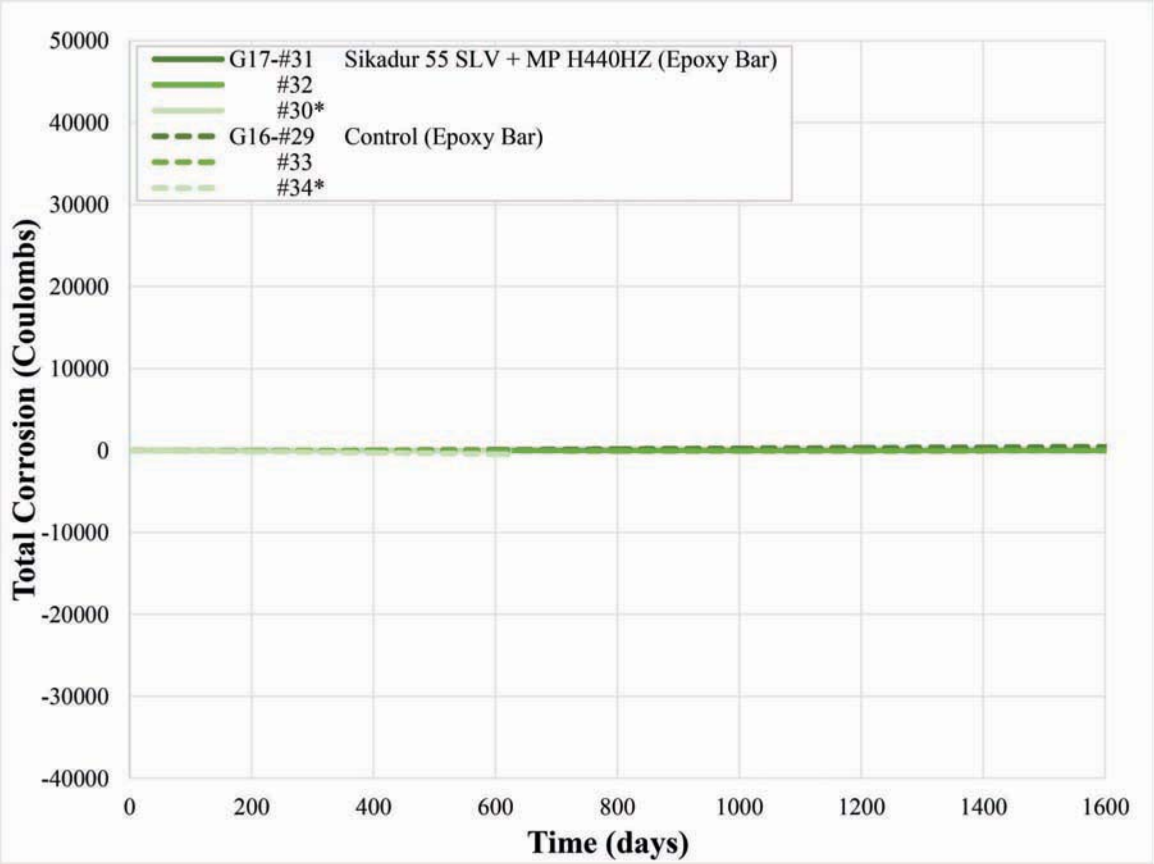


Figure 4.54 Epoxy reinforcement—electrical activity history.

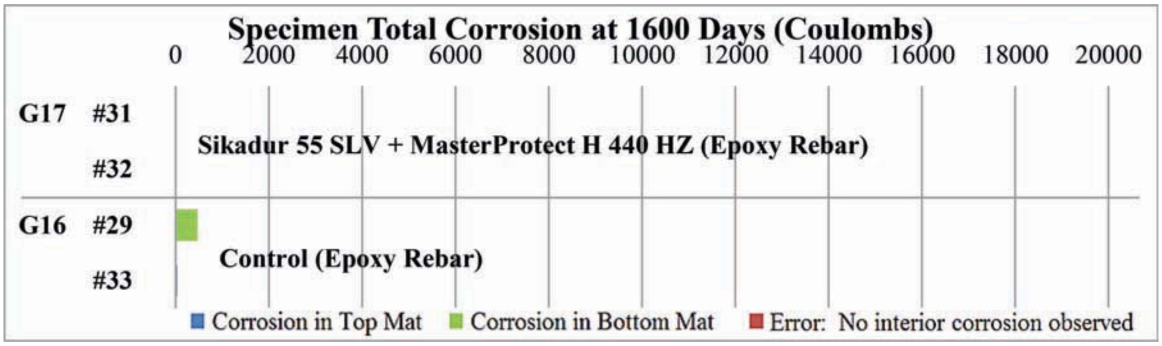


Figure 4.55 Epoxy reinforcement—electrical activity at 1600 days.

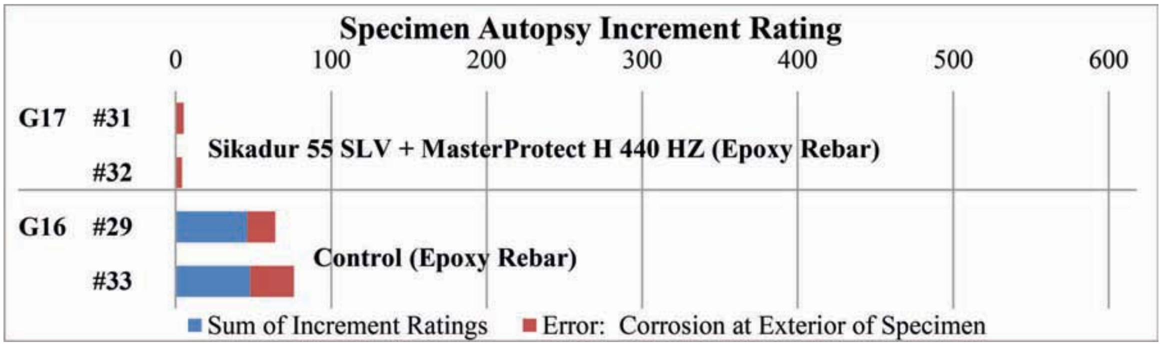


Figure 4.56 Epoxy reinforcement—Autopsy Increment Rating.

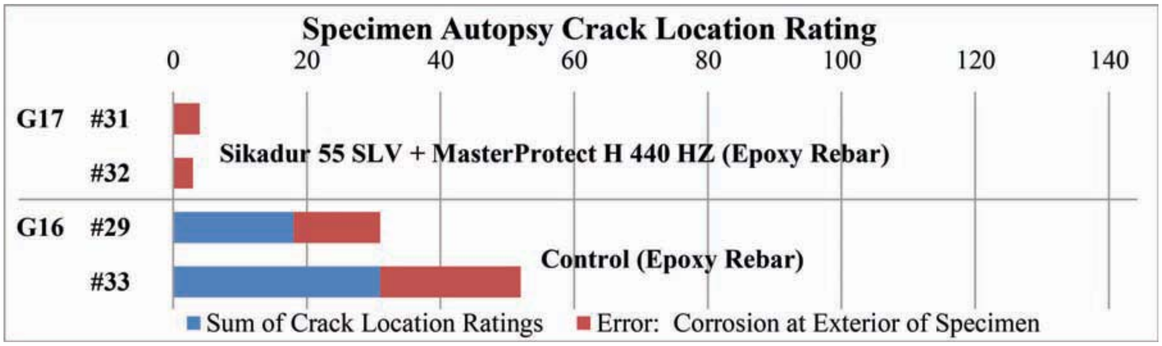


Figure 4.57 Epoxy reinforcement—Autopsy Crack Location Rating.

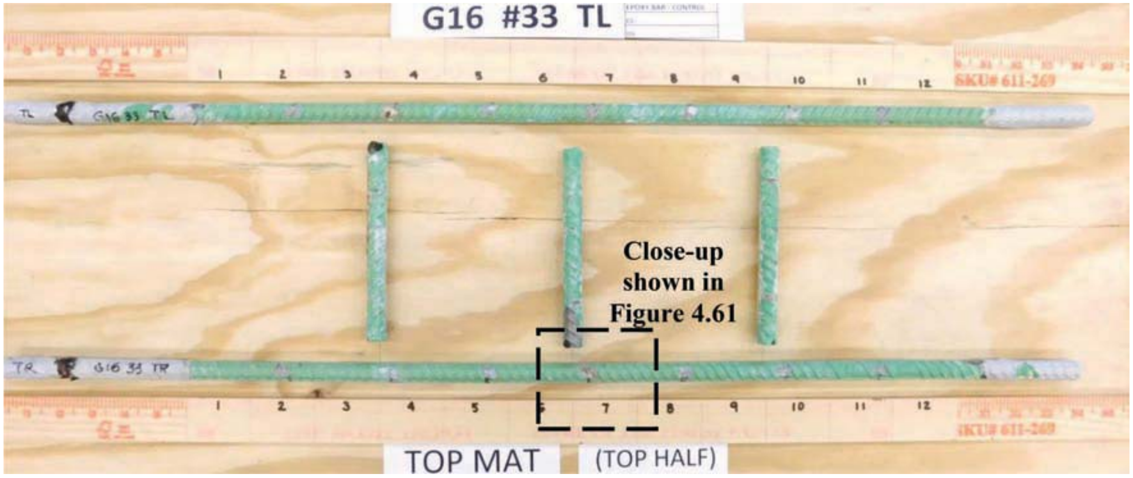


Figure 4.58 Specimen No. 33—top mat at autopsy on March 23, 2016.

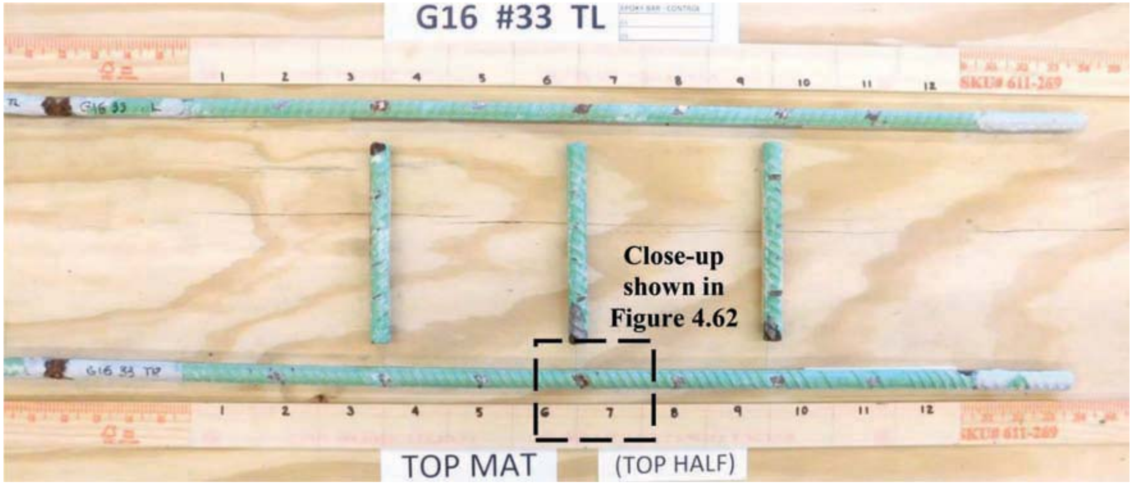


Figure 4.59 Specimen No. 33—top mat before epoxy removal on June 8, 2016.

more vulnerable to chloride intrusion. In spite of this, the tined specimens with the sealer combination did not display electrical activity at 1600 days, as shown in Figure 4.65. Similarly, the autopsy results shown in Figure 4.66 and Figure 4.67 indicate that none of the specimens with the sealer combination exhibited interior corrosion. The combination of Sikadur 55 SLV and MasterProtect H 440 HZ was capable of preventing corrosion in decks regardless of the presence of surface tining.

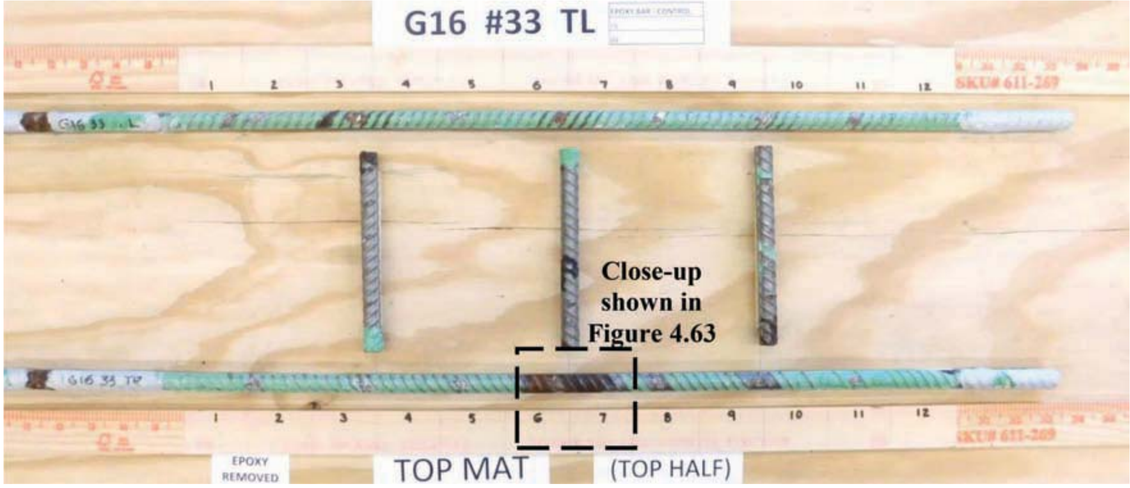


Figure 4.60 Specimen No. 33—top mat after epoxy removal on June 8, 2016.

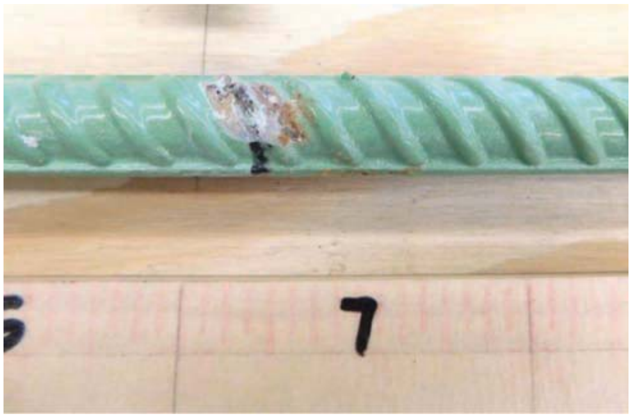


Figure 4.61 Specimen No. 33—close-up at autopsy on March 23, 2016.

Figure 4.63 Specimen No. 33—close-up after epoxy removal on June 8, 2016.

Figure 4.62 Specimen No. 33—close-up before epoxy removal on June 8, 2016.

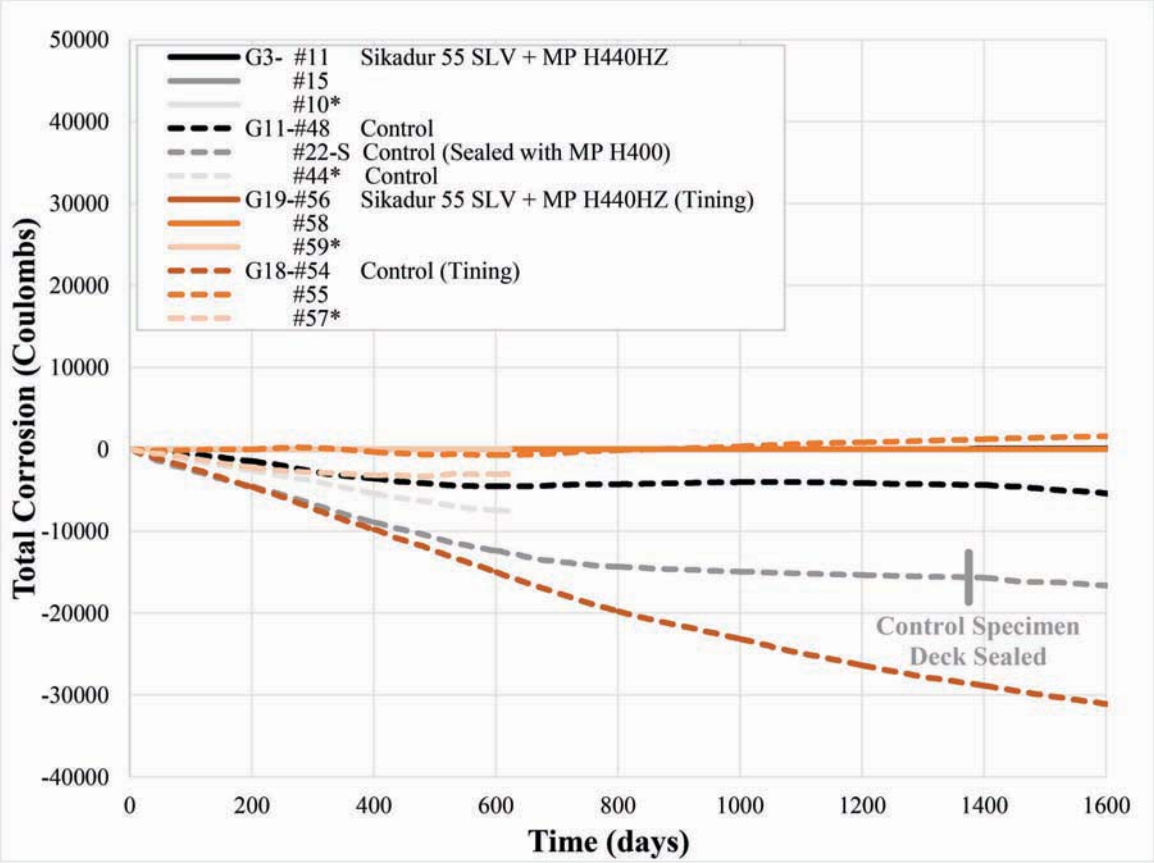


Figure 4.64 Surface tining—electrical activity history.

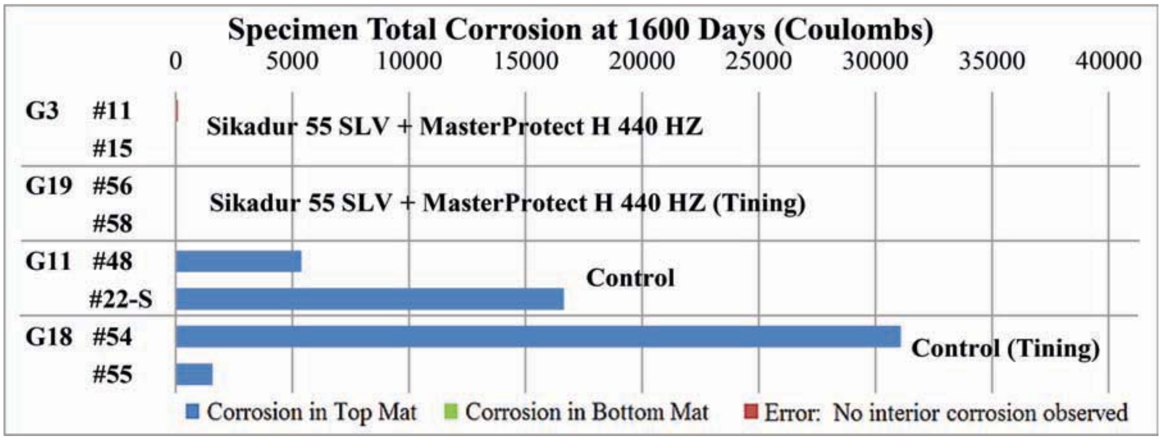


Figure 4.65 Surface tining—electrical activity at 1600 days.

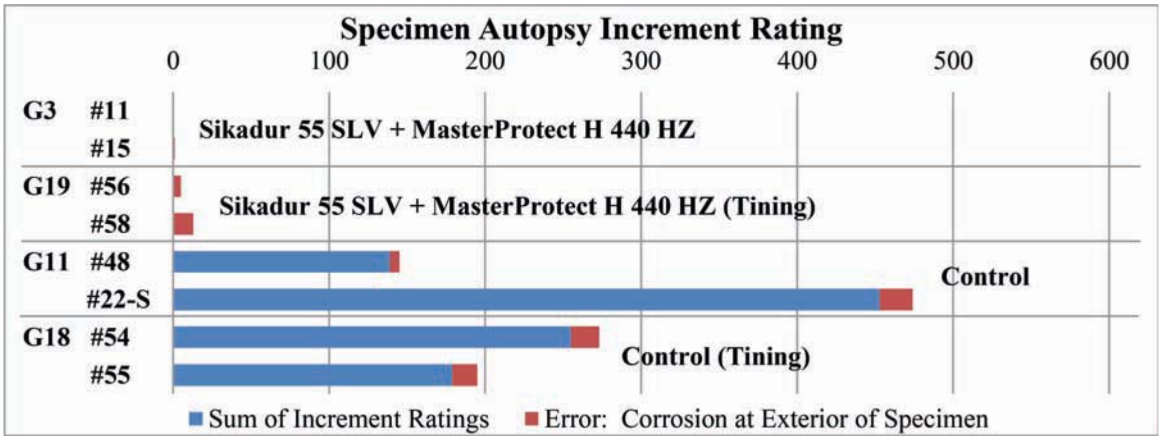


Figure 4.66 Surface tining—Autopsy Increment Rating.

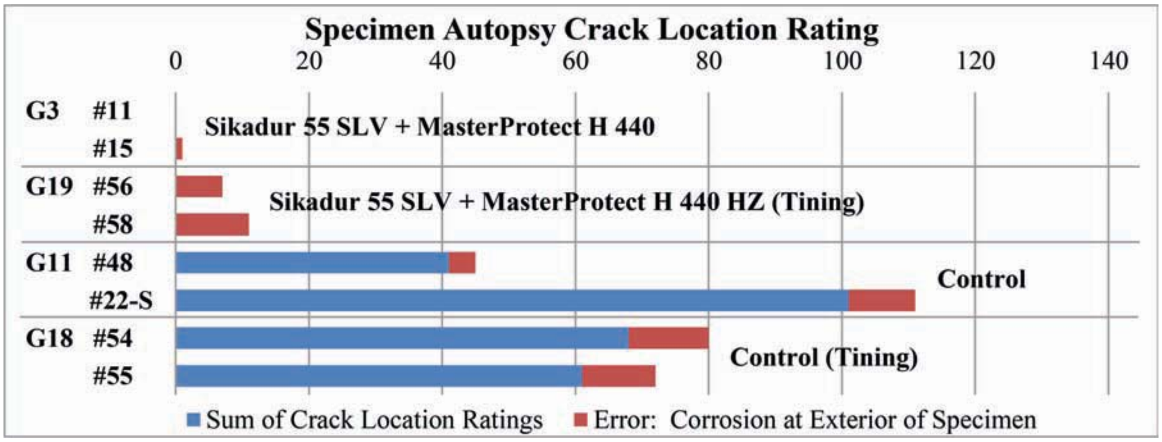


Figure 4.67 Surface tining—Autopsy Crack Location Rating.

4.4 Uncracked Specimens

Groups 20U to 30U consist of uncracked specimens used to investigate the effectiveness of deck sealers in preventing corrosion by reducing salt water ingress through the pore structure of the concrete over time. Group 23U consists of unsealed control specimens, and Group 30U is comprised of unsealed, sandblasted control specimens. A sandblasting depth of 1/16 in. was used for the surface preparation prior to sealer application in Groups 24U to 26U. Similarly, Groups 27U to 29U were sandblasted to a depth of 1/16 in. following sealer application to simulate surface abrasion due to traffic wear.

4.4.1 Deck Sealers (Uncracked)

Groups 20U, 21U, and 22U were treated with the deck sealers MasterProtect H 440 HZ, MasterProtect H 400, and linseed oil, respectively. Their electrical activity history is compared to control Group 23U in Figure 4.68. As seen in Figure 4.69, the deck sealer specimens showed none to negligible amounts of corrosion at 1600 days.

The autopsy ratings shown in Figure 4.70 and Figure 4.71 indicate that any corrosion that occurred in the deck sealer specimens was located only on the ends of the longitudinal bars protruding from the concrete. As a result, electrical activity for these specimens is shown in red in Figure 4.69. Overall, all three deck sealers were effective in preventing the initiation of corrosion up to 1600 days.

4.4.2 Deck Sealer Surface Preparation

Groups 24U, 25U, and 26U investigated the effectiveness of sandblasting the deck to prepare the surface for sealer application. The electrical activity of these groups and the sandblasted control Group 30U is presented in Figure 4.72. The electrical measurements at 1600 days shown in Figure 4.73 indicate corrosion may have occurred in Specimen No. 73. However, the autopsy ratings in Figure 4.74 and Figure 4.75 reveal that there was no interior corrosion in any of the sealed specimens. Thus, the electrical activity displayed by Specimen No. 73 in Figure 4.73 is shown in red. Again, all three deck sealing products proved effective up to 1600 days.

4.4.3 Deck Sealer Traffic Wear

After the deck sealers were applied to the specimens in Groups 27U, 28U, and 29U, the specimen surfaces

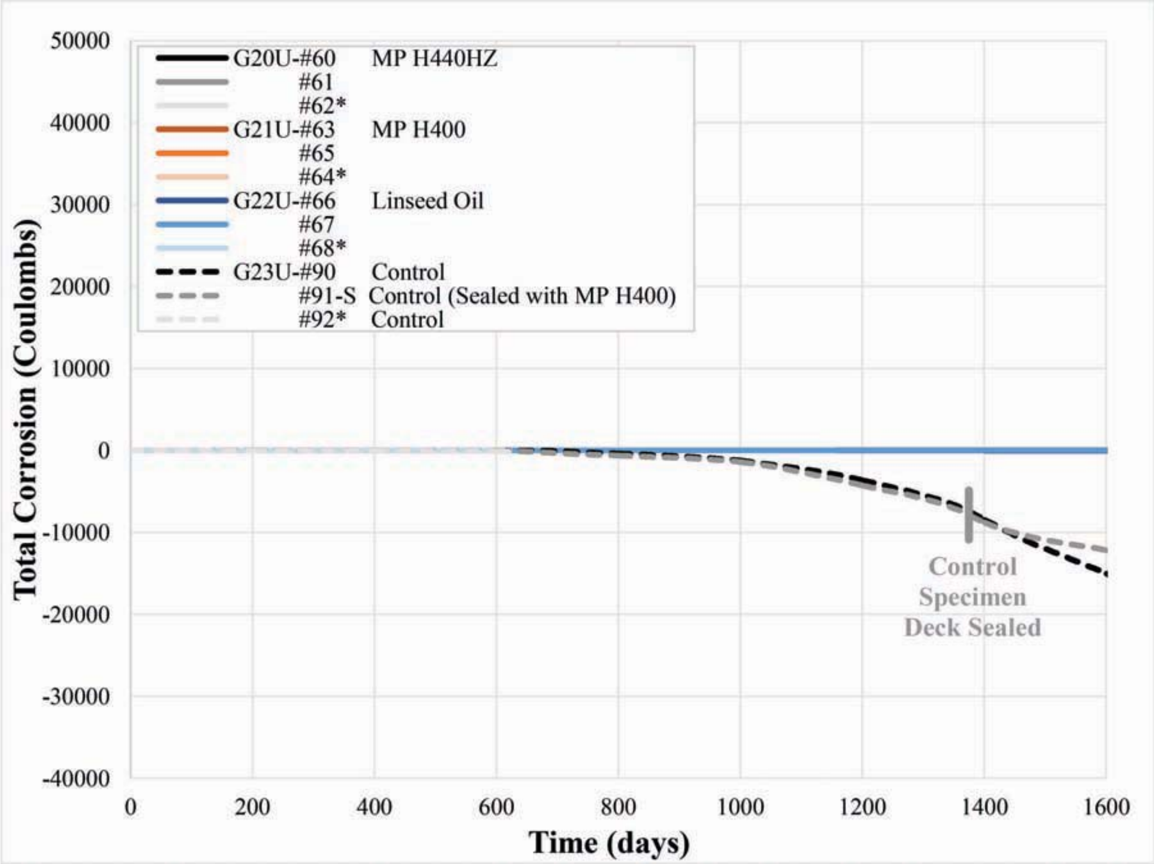


Figure 4.68 Deck sealers (uncracked)—electrical activity history.

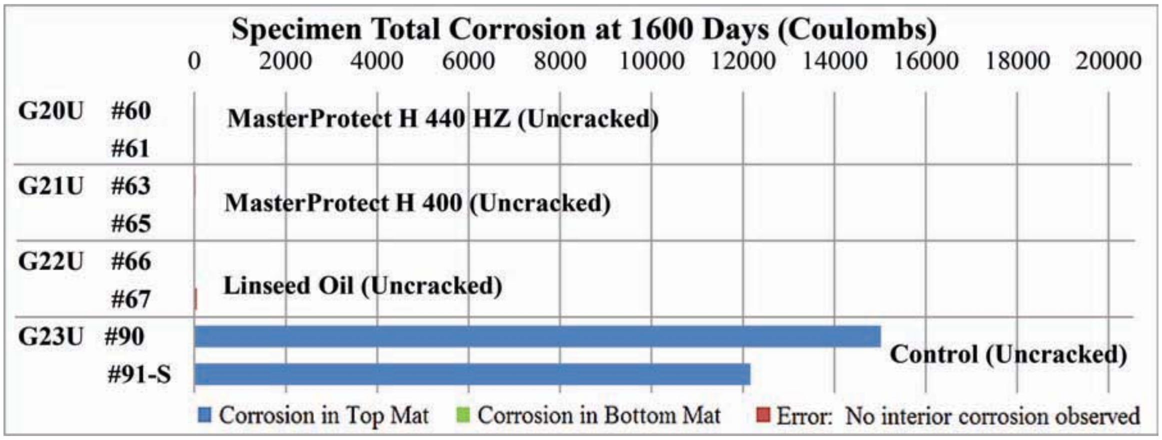


Figure 4.69 Deck sealers (uncracked)—electrical activity at 1600 days.

were sandblasted to simulate abrasion due to traffic wear. Figure 4.76 compares the electrical activity of sealed Groups 27U, 28U, and 29U with the sandblasted control Group 30. Electrical measurements taken at 1600 days, shown in Figure 4.77, indicate mild to moderate corrosion in Groups 27U and 28U, while no corrosion is measured in the linseed oil Group 29U. Similar results are reflected by the autopsy ratings in Figure 4.78 and Figure 4.79. From these electrical measurements and autopsy ratings, it appears that linseed oil has the best penetration and is the most resistant to traffic wear. The effects of traffic wear are investigated further through studies of sealer penetration depth and chloride penetration.

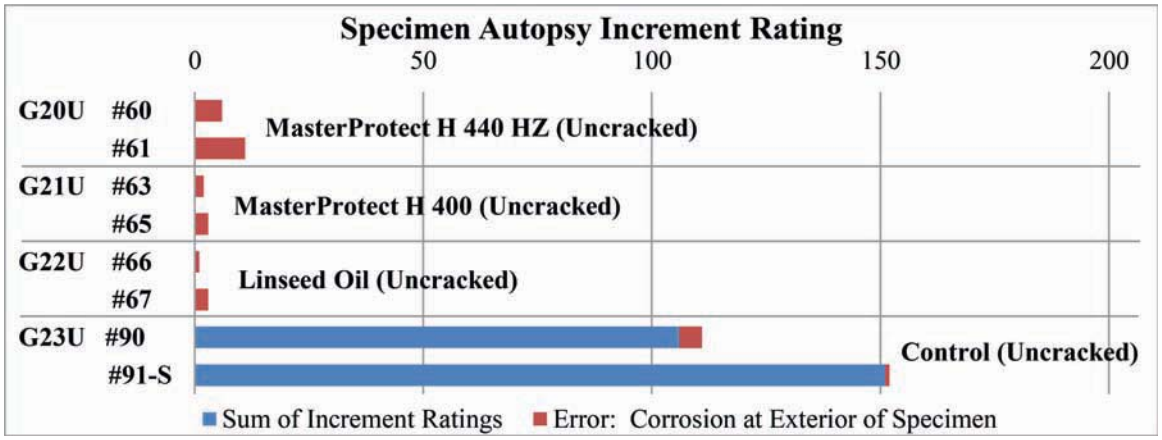


Figure 4.70 Deck sealers (uncracked) by Autopsy Increment Rating.

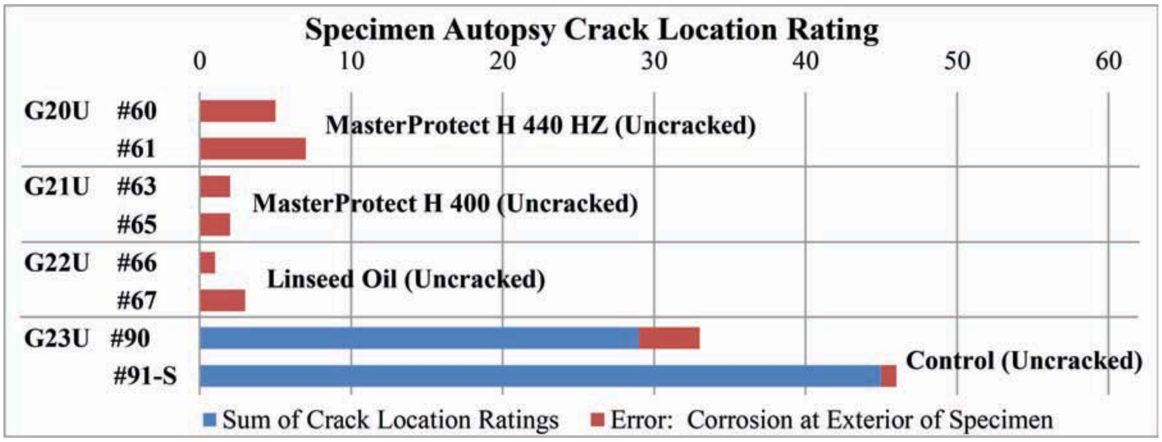


Figure 4.71 Deck sealers (uncracked) by Autopsy Crack Location Rating.

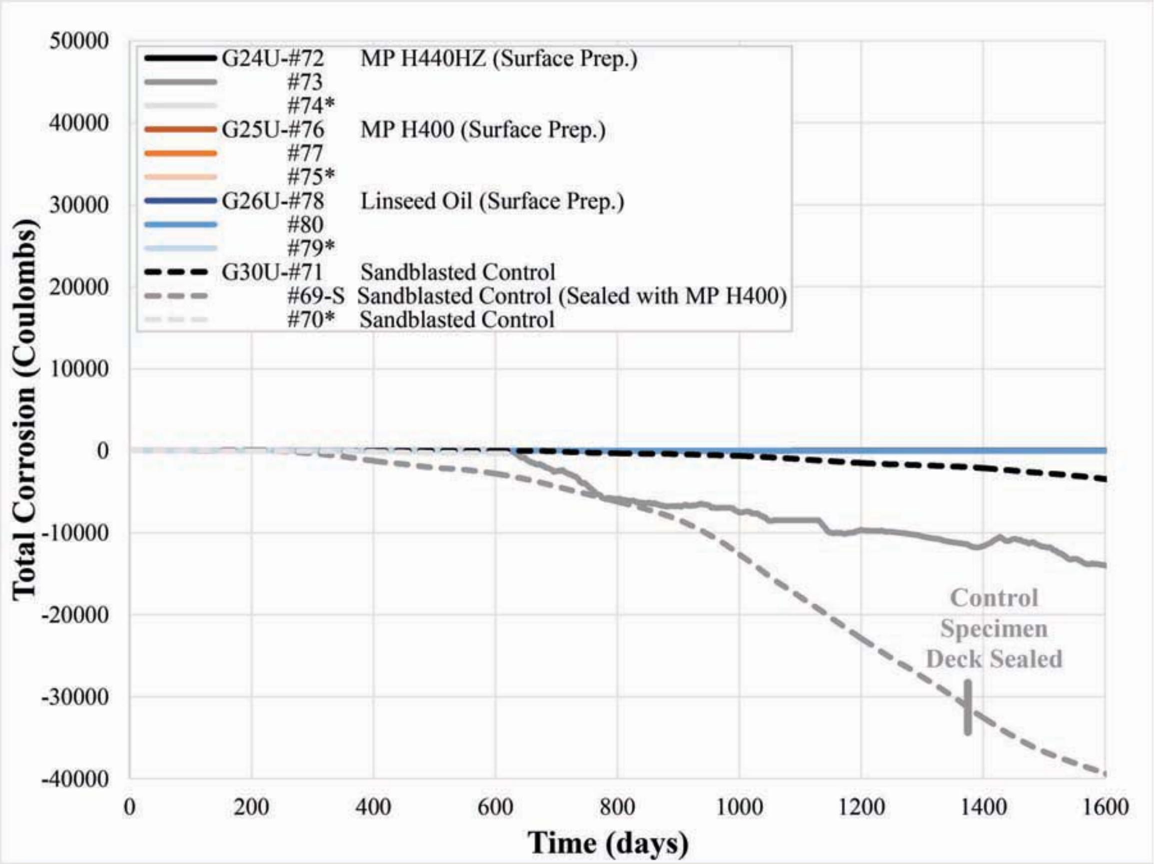


Figure 4.72 Deck sealer surface preparation—electrical activity history.

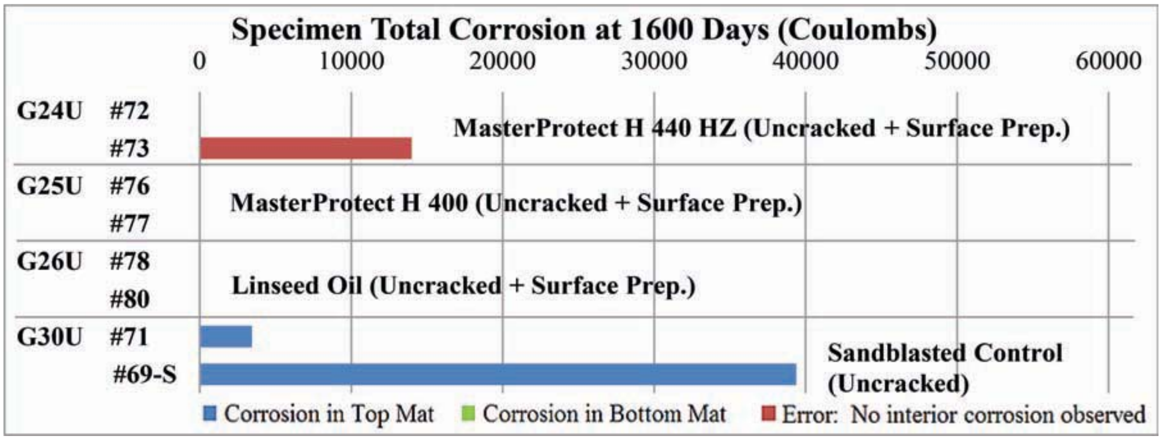


Figure 4.73 Deck sealer surface preparation—electrical activity at 1600 days.

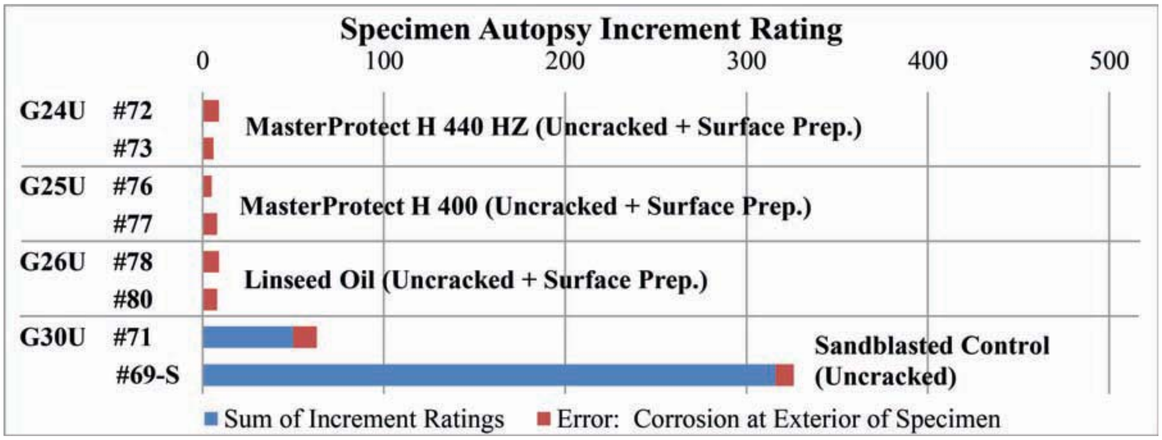


Figure 4.74 Deck sealer surface preparation—Autopsy Increment Rating.

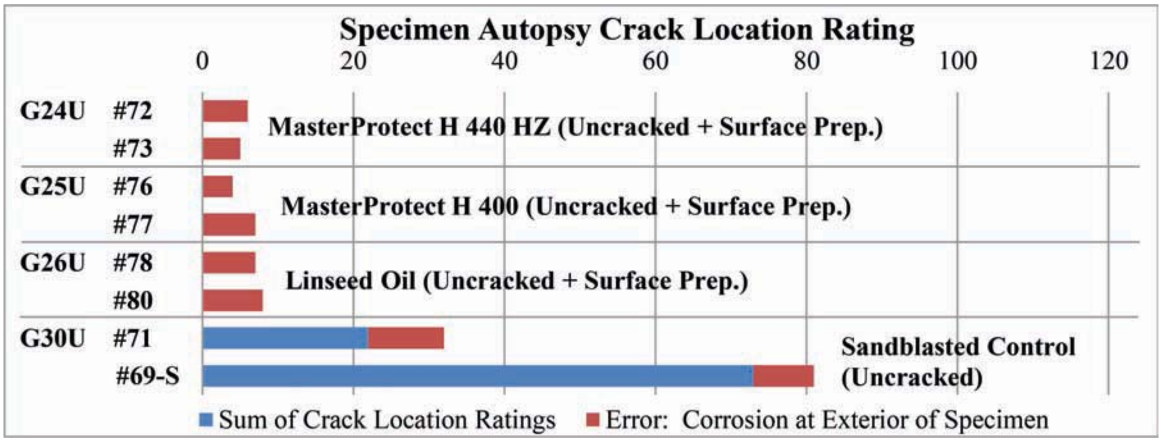


Figure 4.75 Deck sealer surface preparation—Autopsy Crack Location Rating.

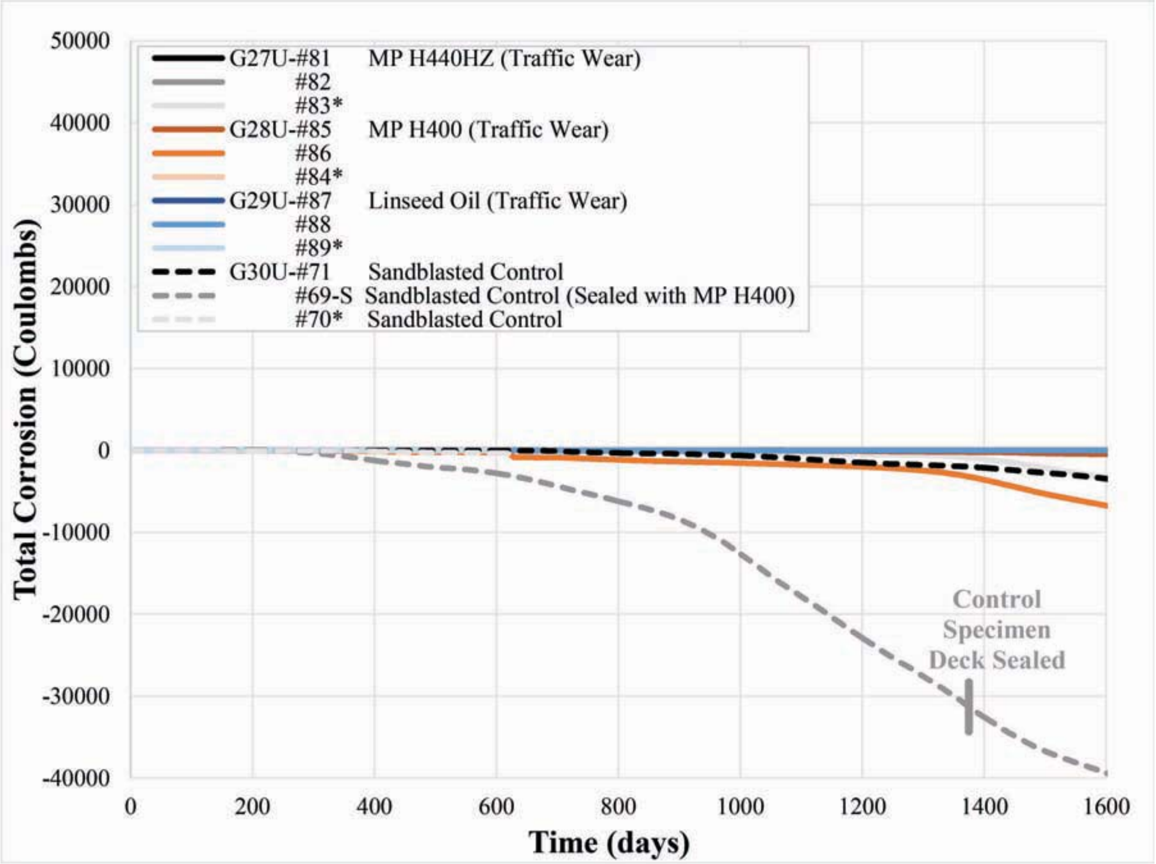


Figure 4.76 Deck sealer traffic wear—electrical activity history.

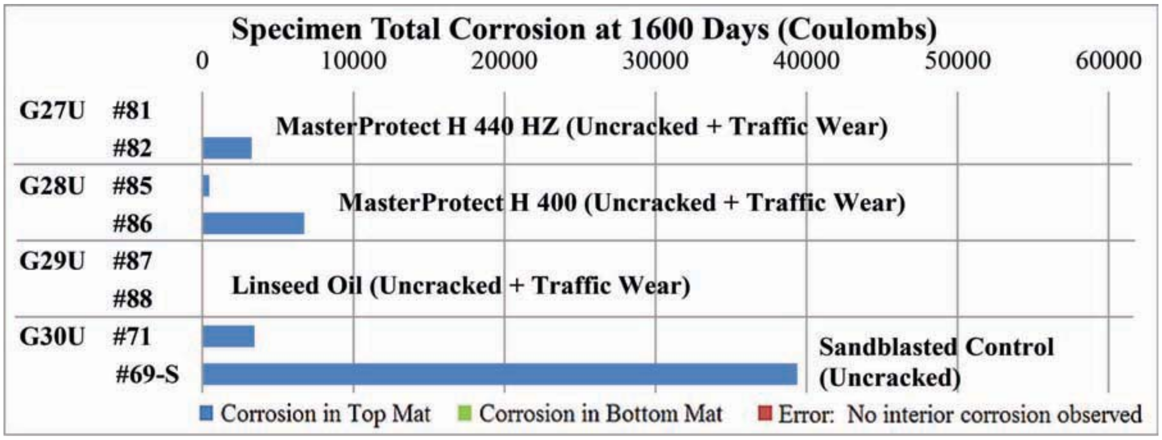


Figure 4.77 Deck sealer traffic wear—electrical activity at 1600 days.

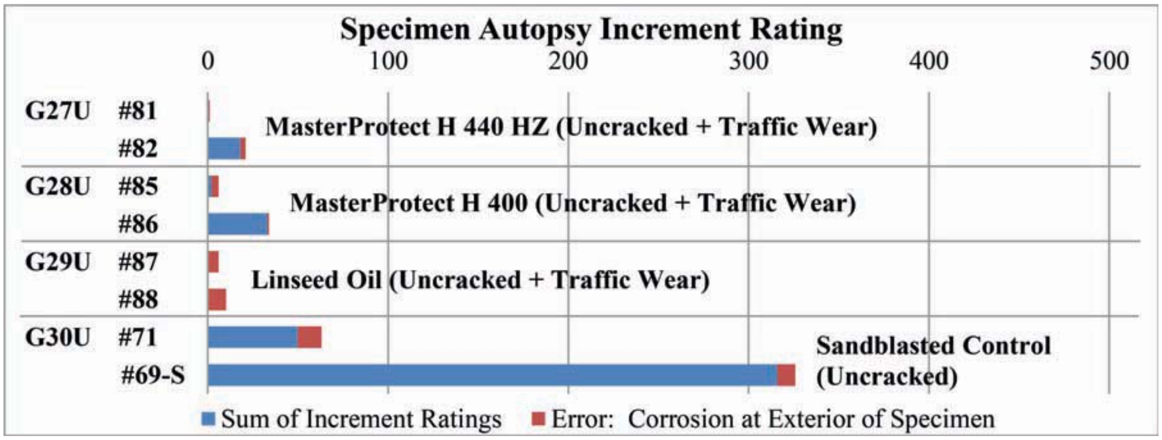


Figure 4.78 Deck sealer traffic wear—Autopsy Increment Rating.

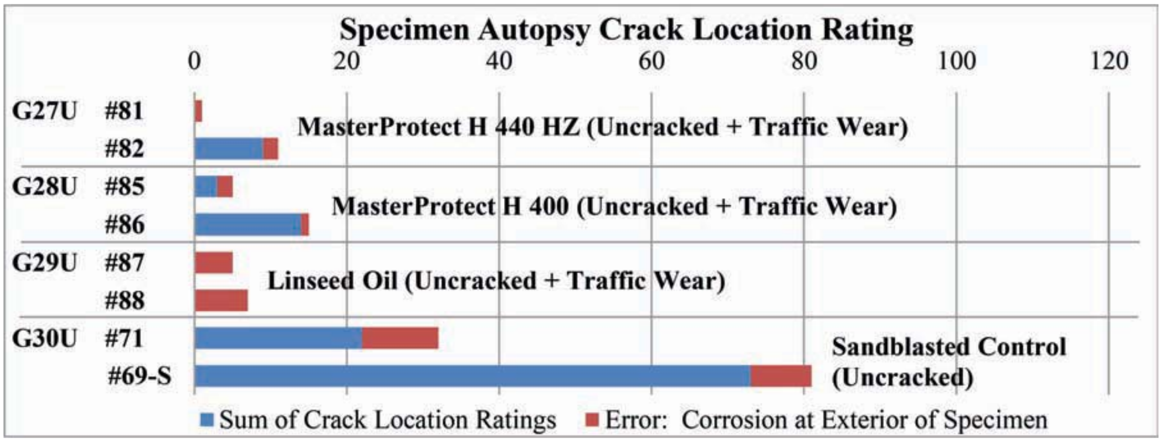


Figure 4.79 Deck sealer traffic wear—Autopsy Crack Location Rating.

4.5 Deck Sealing of Actively-Corroding Control Specimens

Three previously unsealed control specimens were sealed with deck sealer at 1375 days to investigate the effectiveness of deck sealers in slowing the rate of corrosion in actively-corroding specimens. The three specimens were sealed with MasterProtect H 400, a water-based, 40% silane penetrating deck sealer. The specimens included a cracked control (Group 11, No. 22), an uncracked control (Group 23U, No. 91), and a sandblasted uncracked control (Group 30U, No. 69). To extend the length of the investigation, the three specimens remained connected to the datalogger and exposed to the salt water regimen until their autopsy at 1744 days. Measured total corrosion of the three specimens over 1744 days is shown in Figure 4.80, with the date of sealing denoted with a vertical broken grey line at 1375 days. Overall, the deck sealer did not appear to slow the rate of corrosion activity of the specimens. However, it is important to note that the performance of the deck sealer may have been compromised by the existence of cracks in the top surfaces of the specimens, both those in the cracked specimen as well as those formed in the surface of the uncracked specimens due to expansion of the corroding reinforcement. As shown previously in Section 4.3.2, deck sealers are not effective at reducing salt water intrusion at cracked locations. However, given the effectiveness of using a combination of a crack and deck sealer to reduce or eliminate chloride ingress (Section 4.3.3), it is reasonable to conclude that application of a sealer combination has the potential of slowing deterioration of a deck with preexisting corrosion.

4.6 Chloride Penetration

Chloride penetration profiles of deck sealer specimens were developed to investigate the deck sealers' effectiveness in reducing salt water ingress through the pore structure of the concrete surface. Over time, if enough chlorides are able to permeate the concrete to the depth of the reinforcing steel, then the chlorides along with moisture and oxygen will initiate corrosion of the steel. Corrosion of conventional black steel reinforcement is known to occur once a critical level of chloride content is obtained.

Penetration profiles were developed by testing samples of concrete dust drilled from the specimens in increments of 0.25 in. from the top surface to the depth of the longitudinal reinforcement. The specimens autopsied in 2013 were drilled in eight (8) 0.25 in. increments

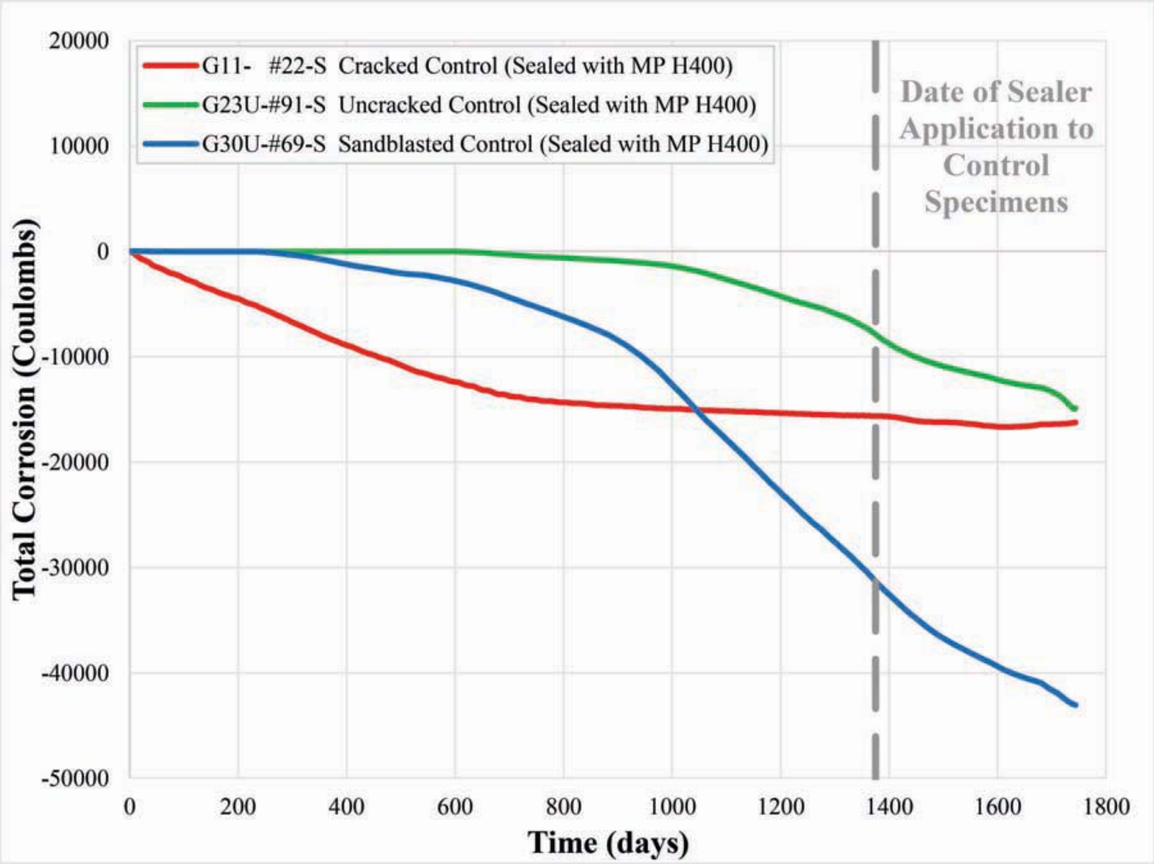


Figure 4.80 Sealer application to corroding control specimens—electrical activity history.

to a total depth of 2 in., the depth of the top of the longitudinal bars. To evaluate the concrete at levels adjacent to the bars, the drilling of the specimens autopsied in 2016 was increased to ten (10) 0.25 in. increments to a total depth of 2.5 in., the depth of the bottom of the longitudinal bars.

Each depth increment was tested using a James Instruments Chlorimeter Test System to determine the chloride content by weight of concrete. Although three holes were drilled to collect dust for each testing increment in an attempt to develop representative test samples, the non-homogeneity of concrete leads to scatter in the results. Consequently, the chloride profiles were used to identify trends regarding the general effectiveness of using sealers, rather than to develop a definitive comparison of the various products.

Chloride penetration profiles were used to compare the chloride levels of the uncracked control specimens and uncracked specimens with deck sealers (MasterProtect H 440 HZ, MasterProtect H 400, and linseed oil). Two specimens from each uncracked group were tested to compare chloride penetration profiles among specimens with smooth surfaces (G20U-G22U), surface preparation (G24U-G26U), and traffic wear (G27U-G29U). The first specimen tested from each group was the specimen that had been autopsied in 2013 and had been exposed to the salt water regimen for only 617 days. The second specimen tested from each group was one of the two specimens autopsied in 2016 after 1600 days of exposure. Furthermore, six cracked specimens from the 2013 autopsy were tested to compare the chloride intrusion of cracked specimens with that of uncracked specimens. Finally, the measured chloride content at the depth of the longitudinal bars in each specimen was compared to the autopsy results to correlate chloride content with the occurrence of corrosion.

To determine the base level of chlorides in the concrete, one uncracked sealed specimen that did not exhibit corrosion was drilled in 0.25 in. increments from the bottom surface to a level of 2 in. above the bottom surface. The chloride content at this depth, 6 to 8 in. below the top surface, is used as an estimate of the chloride content in the concrete prior to exposure testing. The measured values of base chloride content ranged from 1.26% to 1.45% chloride by weight of concrete.

4.6.1 Uncracked Specimens with Deck Sealers (G20U to G23U)

Figure 4.81 presents the chloride penetration profiles for two specimens from each group with applied deck sealers (G20U-G22U) and the uncracked control group (G23U). The figure shows penetration depth on the vertical axis, where a depth of zero penetration at the top of the figure corresponds to the top surface of the concrete. The depths corresponding to the top and bottom

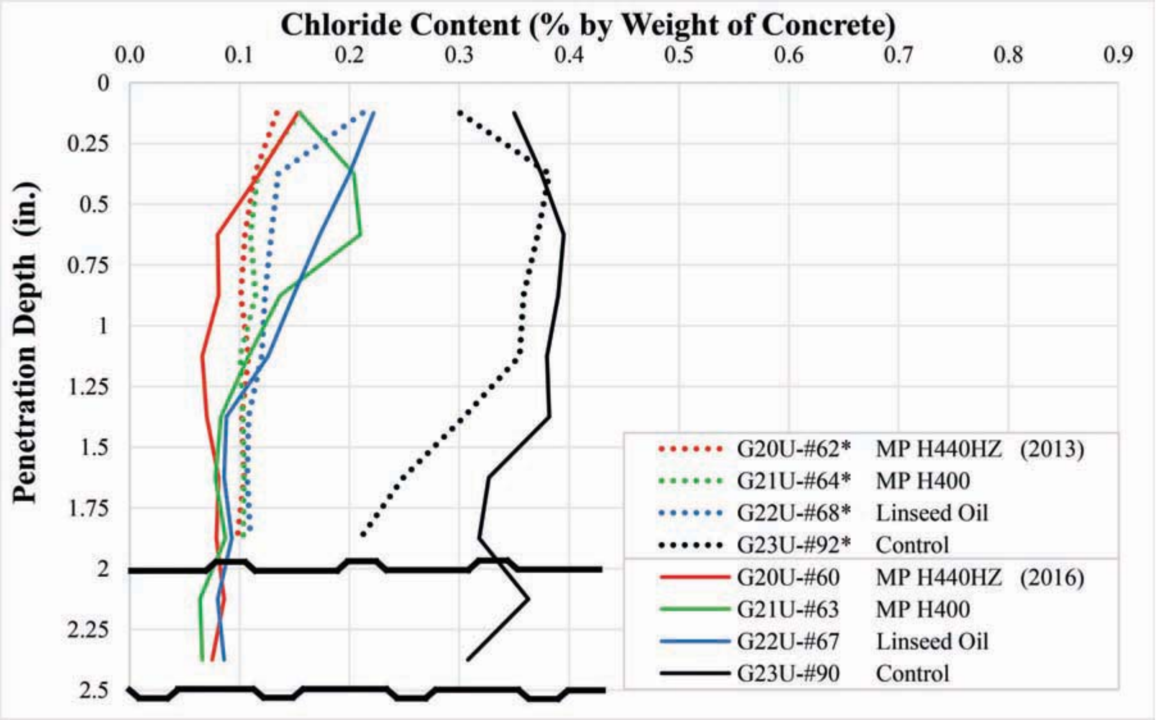


Figure 4.81 Chloride penetration profiles after 617 and 1600 days of exposure for uncracked deck sealer groups.

surfaces of the longitudinal bars in the specimens are represented by an outline of a deformed bar shown with heavy black lines. The top of the bar is at a depth of 2 in. while the bottom of the bar is at a depth of 2.5 in. The horizontal axis measures the percent chloride content by weight of concrete, with chloride content increasing from left to right. The measured value of chloride content for each depth increment is shown at the mid-depth of the increment. For example, the chloride content of the dust collected in a range from 1 in. to a depth of 1.25 in. is shown at a depth of 1.125 in. Although the chloride profile is shown from the top surface to the depth of the reinforcement, it is important to note that the potential for corrosion to occur corresponds only to the percent chloride content at depths adjacent to or immediately above the longitudinal bars.

In Figure 4.81, the specimens in sealed Groups 20U, 21U, and 22U are shown in red, green, and blue, respectively, while the control specimens of Group 23U are shown in black. The specimens with 617 days of exposure from the 2013 autopsy are shown with dotted lines and those with 1600 days of exposure from the 2016 autopsy are displayed with solid lines. As mentioned previously, the 2013 specimens were only tested to a depth of 2 in., while the 2016 specimens were drilled to depth of 2.5 in. As expected, the chloride content generally decreases with increasing depth for each specimen. The concrete at the depth of the reinforcement for the six deck sealer specimens was measured to contain 0.1% chloride by weight of concrete or less, which corresponds to the base level of chloride in the concrete prior to salt water exposure, as discussed in Section 4.6. Therefore, the sealers effectively maintained the chloride content at the level of the reinforcement, which correlates well with the lack of observed corrosion in these sealed specimens. It can also be seen that the performance of the sealers did not deteriorate with extended exposure time, as the profiles at 1600 days are essentially the same as 617 days.

4.6.2 Uncracked Specimens with Surface Preparation (G24U to G26U)

Chloride penetration profiles for specimens with surface preparation in Groups 24U to 26U from the 2013 and 2016 autopsies are presented in Figure 4.82. The control specimens from 2013 and 2016 both exhibited corrosion at the time of autopsy, which correlates with the high chloride concentrations at the depth of the reinforcement. It can be seen that the extended exposure time on the control specimen increased the amount of chloride in the concrete, which corresponded to the increased amount of corrosion in the 2016 specimen. The chloride contents were higher for the control specimens when the surface was prepared (see Figure 4.81 for comparison). In general, however, similar chloride contents were observed for the sealed specimens, regardless of whether the surface was prepared by sandblasting prior to sealing. As shown in Figure 4.82, the chloride profiles did not change from 617 to 1600 days for the sealed specimens with surface preparation, with the only exception being the linseed oil specimen. Low values were measured for both the 2013 and 2016 specimens, which again corresponded to that of the base level chloride content, thus indicating that the sealer performance did not deteriorate over time.

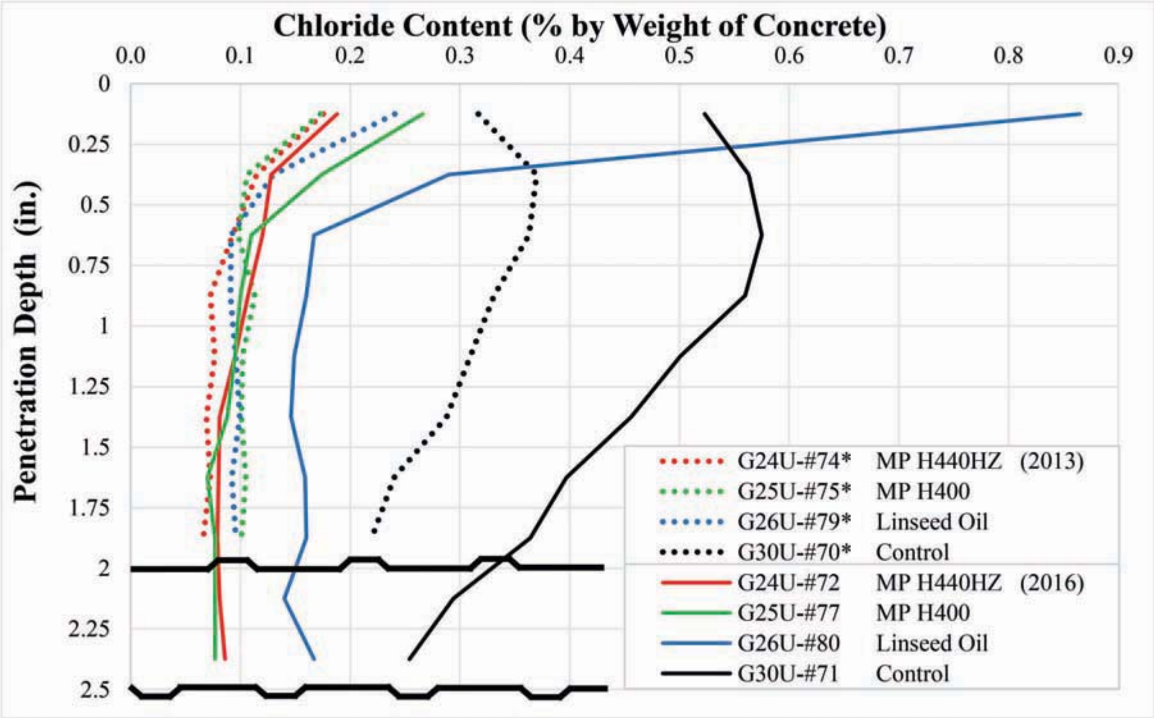


Figure 4.82 Chloride penetration profiles after 617 and 1600 days of exposure for uncracked deck sealer surface preparation

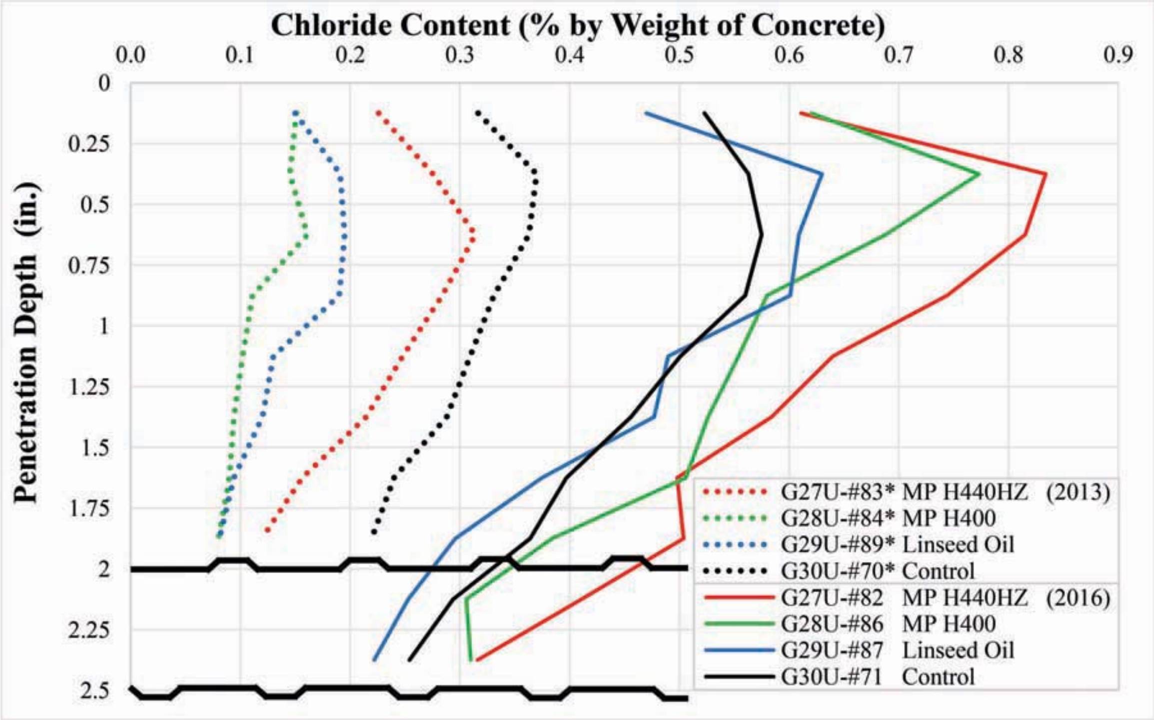


Figure 4.83 Chloride penetration profiles after 617 and 1600 days of exposure for groups (27U, 28U, 29U, and 30U).

4.6.3 Uncracked Specimens with Traffic Wear (G27U to G29U)

The chloride penetration profiles for specimens autopsied in 2013 and 2016 for sealer traffic wear Groups 27U, 28U, and 29U are compared with those of the sandblasted control Group 30U in Figure 4.83. Although the sealer specimens were subjected to 1/16 in. of sandblasting to simulate traffic wear after sealer application, the percent chloride in the specimens autopsied in 2013

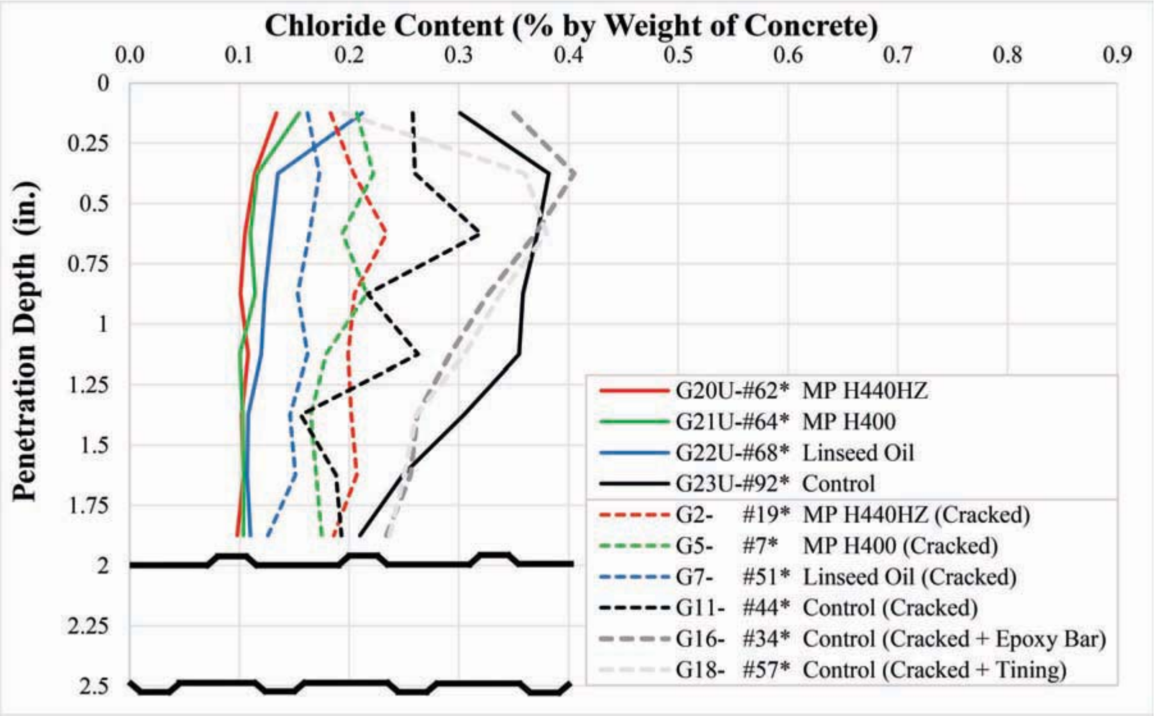


Figure 4.84 Chloride penetration profiles of cracked and uncracked specimens after 617 days of exposure.

remained at the base level of chloride content at the level of the steel. As a result, no corrosion occurred in the sealer specimens with only 617 days of exposure. It should be noted that the chloride levels overall were higher than those previously observed (refer to Figure 4.81 and Figure 4.82). The four specimens with 1600 days of exposure, however, experienced a significant increase in chloride content, again different than previously observed. During the 2016 autopsy, corrosion was observed in the MasterProtect H 440 HZ (red), MasterProtect H 400 (green), and control (black) specimens. All three of these specimens were found to have chloride contents at the depth of reinforcement that largely exceeded the base level of chloride content. The linseed oil specimen (blue) did not exhibit corrosion, despite having a chloride content of as high as 0.25% at the top of the reinforcement. However, this anomaly may be explained by the possibility of having collected a non-representative test sample due to the non-homogeneity of the concrete. Overall, loss of the sealer due to surface removal such as traffic abrasion was found to be detrimental to the performance of the sealer.

4.6.4 Cracked versus Uncracked Specimens

Chloride penetration profiles were developed for both cracked and uncracked specimens with applied deck sealers (Figure 4.84). The specimens tested for this comparison were all specimens that had been autopsied in 2013 after experiencing 617 days of exposure. The uncracked specimens tested included the control, shown by a solid black line, and those with applied deck sealers, shown by solid red, green, and blue lines. The cracked specimens with identical product applications are shown by broken lines with corresponding colors. Chloride penetration profiles for the cracked control with epoxy bar (dark grey) and the cracked control with surface tining (light grey) were also developed as shown in Figure 4.84.

Overall, it is seen that the control specimens, both cracked and uncracked, contained the highest chloride contents at the depth of the reinforcement. As expected, it can also be seen that the broken lines of the sealed cracked specimens showed greater concentrations of chlorides than the sealed uncracked specimens. Clearly, chloride penetration at the cracks migrated inward to the specimen, considering that chloride samples were taken between crack locations.

4.6.5 Correlation of Chloride Penetration Testing and Observed Corrosion

The chloride content at the depth of the longitudinal reinforcing bar for each tested specimen is presented in Figure 4.85. The chloride content shown for each specimen is at a depth increment of 1.75 in. to 2 in. To the right of the bars representing the chloride content at the depth of the reinforcement, each specimen that exhibited interior corrosion at autopsy is denoted with “C,” while specimens with no corrosion are marked with “NC.” An approximation of the average base level of chloride content in the concrete is shown by a broken red line. This value, based on the various specimens, is considered as approximately 0.1% chloride by weight of concrete.

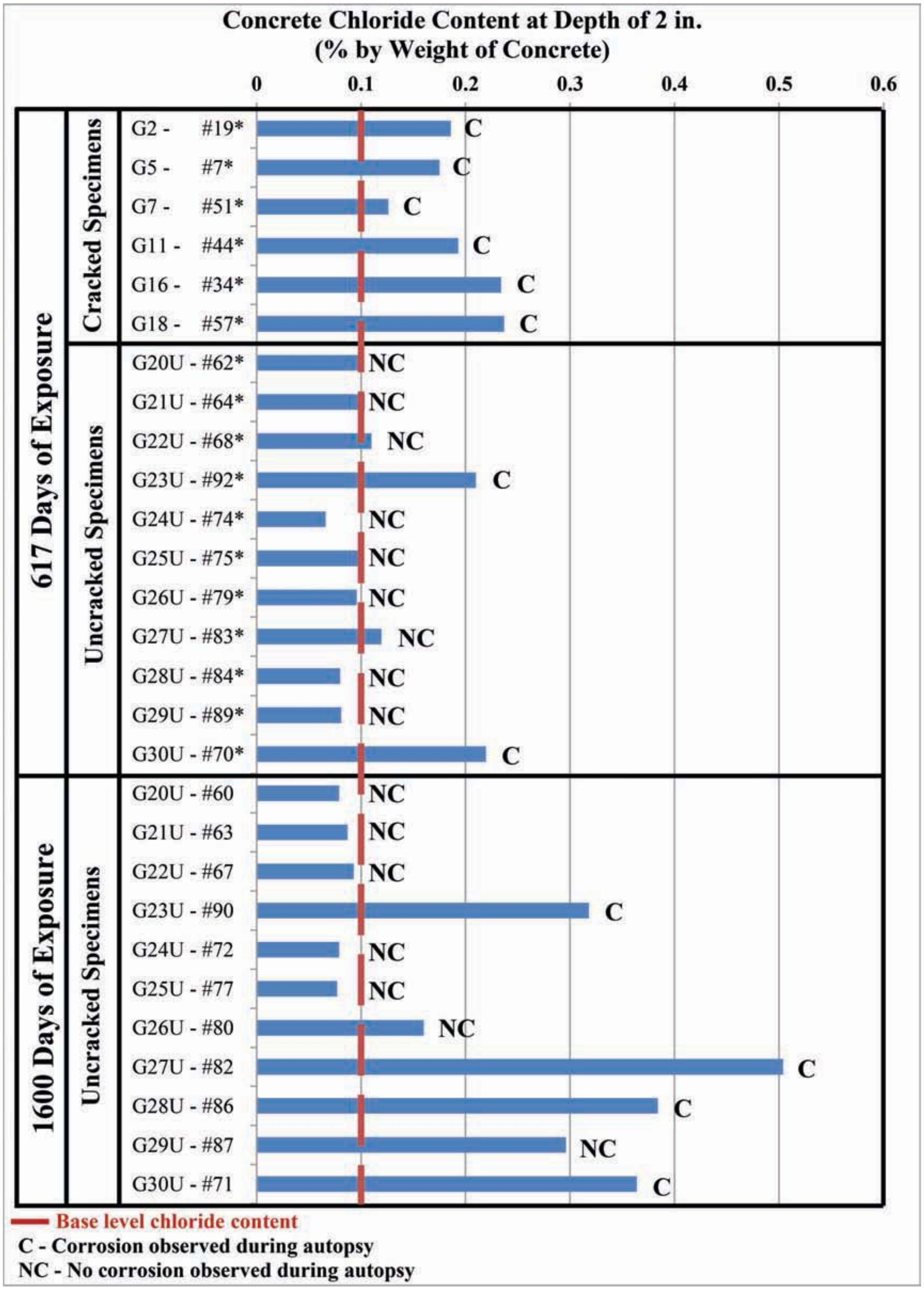


Figure 4.85 Correlation of chloride penetration and observed corrosion.

In general, the uncracked specimens from 2013 and 2016 were shown to exhibit corrosion only if their chloride content at the reinforcement significantly exceeded the base level chloride content. The only exception was the absence of corrosion in Specimen No. 87 from Group G29U. Despite having a chloride content greatly exceeding the base level chloride content, corrosion was not observed. However, as discussed in Section 4.6.3, this anomaly may be attributed to variability in the chloride threshold as well as expected variability of the chloride test results due to the non-homogeneity of the concrete.

Several of the cracked specimens exhibited corrosion despite having lower chloride content levels; however, this is expected, due to the positioning of the dust collection holes in cracked specimens. Because the dust collection holes in cracked specimens were located halfway between the cracked locations to avoid drilling at an edge, the samples tested do not contain as high a chloride content as what would be present immediately adjacent to a crack. At cracks, chlorides in the salt water were able to penetrate directly to the depth of the reinforcement to initiate corrosion. Therefore, even though some of the chloride test samples contained chloride concentrations similar to the base level of chloride content, the autopsies revealed corrosion at the crack locations where there was a higher concentration of chlorides.

4.7 Deck Sealer Penetration Depth

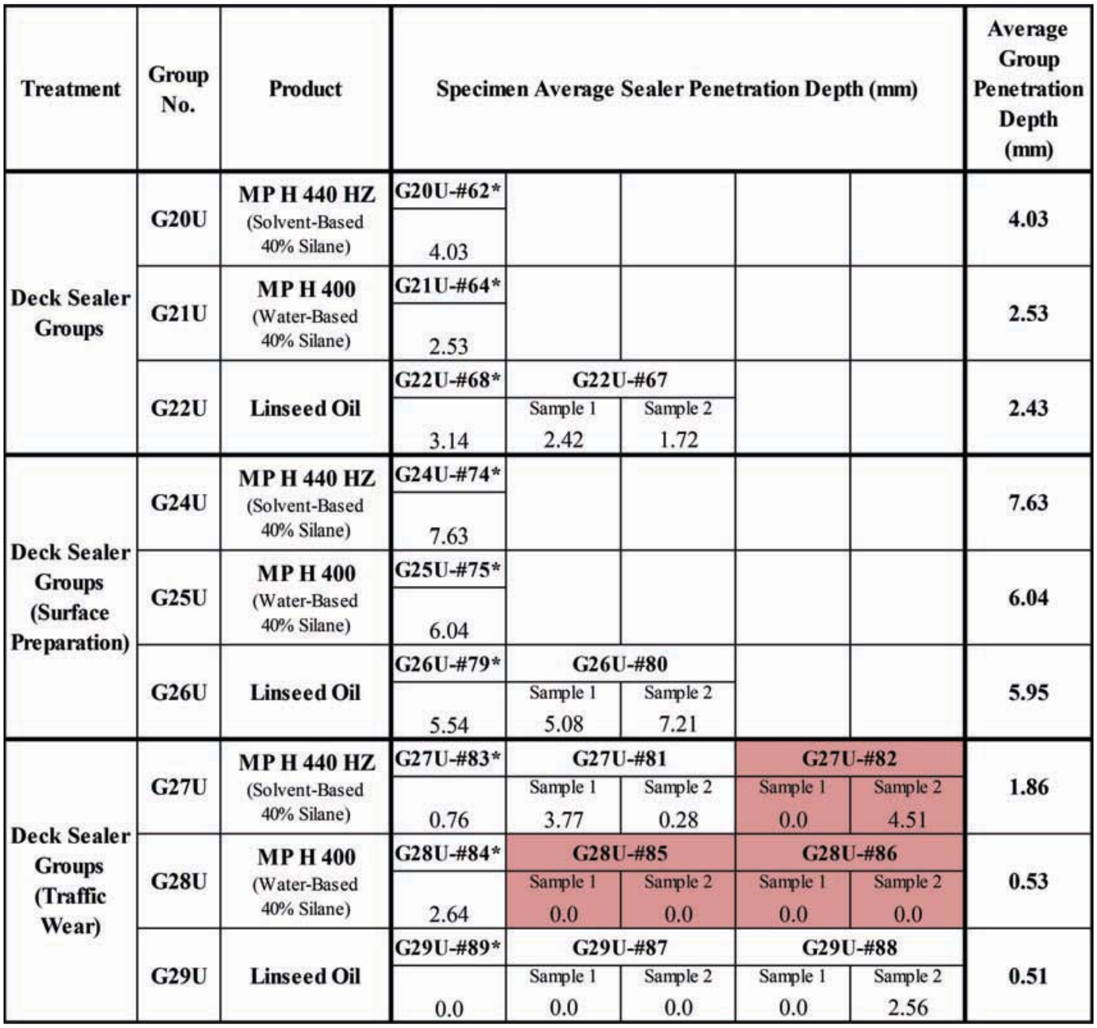
Deck sealer penetration depth was measured for at least one specimen in each uncracked group. For this investigation, the salt water exposure time of the specimens was irrelevant because all specimens of each group were sealed at the same time during specimen preparation in 2011. Furthermore, the same sealer application method was used for all three specimens in each group in an attempt to have consistent coverage. The penetration depths of the two silane products, MasterProtect H 440 HZ and MasterProtect H 400, were easily identified by spraying the concrete cross-section with water, and using a caliper to measure the depth of concrete that remained dry in the area of the absorbed sealer. It was necessary to use another method to measure the penetration of linseed oil; therefore, ultraviolet light was used to illuminate areas with linseed oil penetration. A minimum of six depth measurements were taken across the 3.5 in. width of each specimen sample. The measurements were then averaged for each specimen, and an average depth of sealer penetration was calculated for each specimen group. Figure 4.86 shows the average sealer penetration depths for each tested specimen and each group. Specimens were tested from each of the three application conditions, including the deck sealer specimens (G20U-G22U), surface preparation specimens (G24U-G26U), and traffic wear specimens (G27U-G29U).

The relative penetration of the three products was consistent for each of the three application conditions. MasterProtect H 440 HZ specimens (G20U, G24U, and G27U) were shown to have the best penetration in each condition. MasterProtect H 400 and linseed oil displayed essentially the same penetration depths in each condition, although linseed oil penetration was slightly less than that of MasterProtect H 400.

When comparing the performance of deck sealers in each condition, as shown in Figure 4.87, it was found that the 1/16 in. of sandblasting for surface preparation (G24U-G26U) resulted in sealer penetration depths for all three sealers that nearly doubled those of the smooth-surfaced specimens (G20U-G22U).

The sealer penetration depths that remained after 1/16 in. of sandblasting to simulate traffic wear displayed inconsistent results among the specimens tested in each group, as shown in Figure 4.86. For example, when examining two samples from different locations of the same specimen, one would show minimal to no evidence of remaining sealer penetration, while the other would show as much as 4.5 millimeters of penetration. This occurred in Specimens No. 81 and 82 of Group 27U, as well as Specimen No. 88 in Group 29U. In other instances, the sealer is shown in penetrate in only one of the three specimens in the group, such as No. 84 in Group 28U and No. 88 in Group 29U. Furthermore, the sealer penetration depths do not always correlate with the amount of corrosion observed during autopsy. The specimens shown in red in Figure 4.86 are those that displayed corrosion during autopsy. The lack of sealer penetration in one or both samples from Specimen Nos. 82, 85, and 86 corresponds directly to the observed corrosion in those specimens; however, the linseed oil specimens in Groups 29U did not display observed corrosion or measured electrical current while measuring zero depth of sealer penetration in four out of the five examined samples.

It is likely that the discrepancies noted in Groups 27U to 29U can be attributed to several sources. First, it appears that the sealer penetration depth may be rather inconsistent. It is also possible that variations in the sandblasting depth across the specimens may have removed more sealer from some areas of the surface than others. Finally, the determination of sealer penetration into the paste portions of the concrete at the top surface of the specimens was impeded by the presence of aggregates revealed at the top surface by the sandblasting operation.



Treatment	Group No.	Product	Specimen Average Sealer Penetration Depth (mm)					Average Group Penetration Depth (mm)
Deck Sealer Groups	G20U	**MP H 440 HZ** (Solvent-Based 40% Silane)	**G20U-#62***					**4.03**
			4.03					
	G21U	**MP H 400** (Water-Based 40% Silane)	**G21U-#64***					**2.53**
			2.53					
	G22U	**Linseed Oil**	**G22U-#68***	**G22U-#67**				**2.43**
				Sample 1	Sample 2			
			3.14	2.42	1.72			
Deck Sealer Groups (Surface Preparation)	G24U	**MP H 440 HZ** (Solvent-Based 40% Silane)	**G24U-#74***					**7.63**
			7.63					
	G25U	**MP H 400** (Water-Based 40% Silane)	**G25U-#75***					**6.04**
			6.04					
	G26U	**Linseed Oil**	**G26U-#79***	**G26U-#80**				**5.95**
				Sample 1	Sample 2			
			5.54	5.08	7.21			
Deck Sealer Groups (Traffic Wear)	G27U	**MP H 440 HZ** (Solvent-Based 40% Silane)	**G27U-#83***	**G27U-#81**		**G27U-#82**		**1.86**
				Sample 1	Sample 2	Sample 1	Sample 2	
			0.76	3.77	0.28	0.0	4.51	
	G28U	**MP H 400** (Water-Based 40% Silane)	**G28U-#84***	**G28U-#85**		**G28U-#86**		**0.53**
				Sample 1	Sample 2	Sample 1	Sample 2	
			2.64	0.0	0.0	0.0	0.0	
	G29U	**Linseed Oil**	**G29U-#89***	**G29U-#87**		**G29U-#88**		**0.51**
				Sample 1	Sample 2	Sample 1	Sample 2	
			0.0	0.0	0.0	0.0	2.56	

Figure 4.86 Average specimen and group deck sealer penetration.

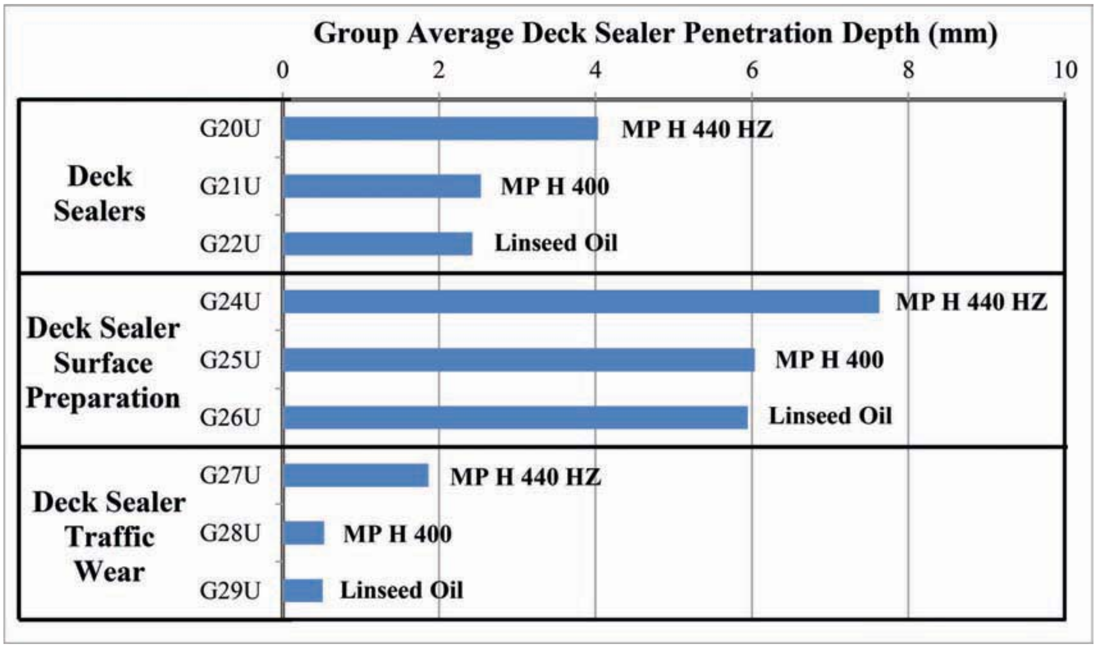


Figure 4.87 Average group deck sealer penetration.

5. FIELD IMPLEMENTATION

5.1 Introduction

Preliminary field tests of crack sealer and deck sealer applications were completed in the fall of 2015. The product selected for crack sealing was Sikadur 55 SLV, a low-viscosity epoxy. MasterProtect H 400, a water-based 40-percent silane, was selected as a deck sealer. The purpose of these preliminary field tests was to identify the personnel, equipment, and procedures required to apply the sealer products efficiently and effectively to a bridge deck in the field.

5.2 Field Test of Crack Sealer

Sikadur 55 SLV is a two-component epoxy with a 2:1 mixing ratio of Part A to Part B. After mixing the components, the material has a pot life of only 20 minutes until the time the epoxy becomes too viscous to install at cracks. Therefore, the entire volume of mixed material must be used prior to the 20-minute pot life. Consequently, simply mixing the epoxy in a pail generates extensive product waste and an inconsistent quality of material over the pot life, with the potential of poor quality material being installed. The unequal mixing ratio and short pot life informed the careful selection of equipment to be used to install this type of product.

5.2.1 Crack Sealer Equipment

In 2014, the Minnesota Department of Transportation (MnDOT) successfully employed the use of a two-component pump for the installation of Sikadur 55 SLV in the field (Oman, 2014). Several styles of pumps similar to that used by MnDOT were compared, resulting in the purchase of a SealBoss JointMaster Pro2 two-component joint filler pump.

The SealBoss JointMaster Pro2 pump motor, chemical reservoir tanks, and battery power source are all contained on a portable cart with four braking swivel wheels (Figure 5.1). Although the pump typically features a standard 1:1 mixing ratio, various ratios can be accommodated with this pump. This specific pump unit was purchased with a 2:1 gear ratio, allowing the pump to mix at a 2:1 ratio. The apparatus includes two, 5-gallon stainless steel reservoir tanks, each used to store one of the two chemical components of the epoxy. After the tanks are filled, the motor pumps the chemicals to drain from each tank and into their respective hoses. The hoses are encased in a protective sleeve extending 14.5 ft from the cart to an applicator wand. The two chemical components first come into contact with each other at a disposable static mixer attached to the end of the applicator wand. The two components are mixed as they flow through the interior grooves of the static mixer (Figure 5.2).

This type of pump system has several features. The amount of product waste is minimized, as the two components are only combined within the disposable static mixer. Furthermore, any material remaining in the tanks and hose lines after sealing can be returned to the product containers for future use. Although the manufacturer of Sikadur 55 SLV recommends conditioning the sealer components to a range of 65° to 75° F

Figure 5.1 SealBoss JointMaster Pro2 pump.

Figure 5.2 Applicator wand and attached static mixer.

prior to installation, it is possible for sealing to be done in cooler weather because heater bands (shown in Figure 5.1) can be attached to the reservoir tanks to keep the product warm. The use of a self-contained battery power source eliminates the encumbrance of using extension cords or a generator on the bridge deck. The controls for the pump are located on the applicator wand, allowing the operator to regulate the rate of product flow from the tip of the static mixer. Finally, because the entire apparatus is contained on a wheeled cart, it is possible for the crack sealer installation to be a single-person operation.

5.2.2 Crack Sealer Field Test

The preliminary field test for installing crack sealer Sikadur 55 SLV occurred on October 29, 2015, on a bridge carrying two lanes of southbound Hoosier Heartland Highway in Tippecanoe County, Indiana (INDOT Structure No. 025-79-02718 SBL). A traffic control team was used to divert traffic into the left traffic lane. The right shoulder was used as a staging area prior to sealing cracks in the right traffic lane. The air temperature at the time of sealing was 40° F, the minimum installation temperature recommended by the sealer manufacturer. Due to the cool temperature, only two cracks were sealed as a demonstration of the equipment and installation procedure.

Prior to sealing, the cracks to be sealed were cleaned with compressed air, as shown in Figure 5.3. The two components of Sikadur 55 SLV, Part A and Part B, were poured into their respective stainless steel reservoir tanks (Figure 5.4). The static mixer was attached to the end of the applicator wand, and the product was pumped into a bucket (Figure 5.5) until it appeared that the proper mixing of the two components had been achieved. The applicator wand and attached static mixer were used to seal two cracks in the bridge deck, as seen in Figure 5.6. Finally, the sealed cracks were covered with sand to prevent vehicle tires from spreading the sealer across the deck (Figure 5.7). The lane closure was reopened after a period of one hour following crack sealer installation.

5.2.3 Recommendations

Overall, this installation method was found to be both efficient and effective. This type of pump minimizes product waste when installing a two-part epoxy. In addition, after the initial equipment setup, this pump system allows for continuous sealing across the bridge deck with only a few short interruptions to refill the reservoir tanks.

In general, it is recommended that dust and debris are cleaned from the cracks using compressed air prior to sealing to allow the product access to the cracks. When sealing a multitude of cracks over a large area, it will be necessary to identify the crack pattern prior to sealing and to develop an installation plan to avoid wheeling the pump cart through wet sealer. Finally, it is critical that the pump setup and cleanup procedures are executed exactly as recommended by the pump manufacturer. These procedures prevent unwanted mixing of the two product components, which could block the flow of product through the tanks and hoses. Following the procedures to keep the pump lines clean will prolong the life of the equipment.

Because this field test was completed at a temperature of 40° F, it was found that cooler air temperatures may lessen the effectiveness of the sealing operation. Cool weather has two effects on the operation: the sealer can become too viscous to achieve full penetration of the

Figure 5.3 Using compressed air to clean the cracks.

Figure 5.4 Pouring sealer components into reservoir tanks.

Figure 5.5 Ensuring proper mixing of sealer components.

cracks and the product curing time is extended. Furthermore, even though the mixing temperature can be controlled by heater bands, the deck temperature remains cold which can change the sealer viscosity upon contact with the deck.

Additional steps must be taken in cooler weather to ensure the effectiveness of the sealing, thus reducing the efficiency of the operation. First, the pails of the product must be kept warm prior to use. When heater bands are used, it is recommended that thermometers be attached to the exterior of the reservoir tanks to regulate the temperature of the product prior to installation.

Considering the additional steps required in cold weather and the potential decrease of sealer penetration in a cold deck, however, it is recommended that crack sealers be installed in higher temperatures, preferably greater than 60° F.

5.3 Field Test of Deck Sealer MasterProtect H 400

The preliminary field test of application of the deck sealer MasterProtect H 400 took place on September 22, 2015, on a bridge carrying two lanes of northbound traffic in Spencer County, Indiana (INDOT Structure

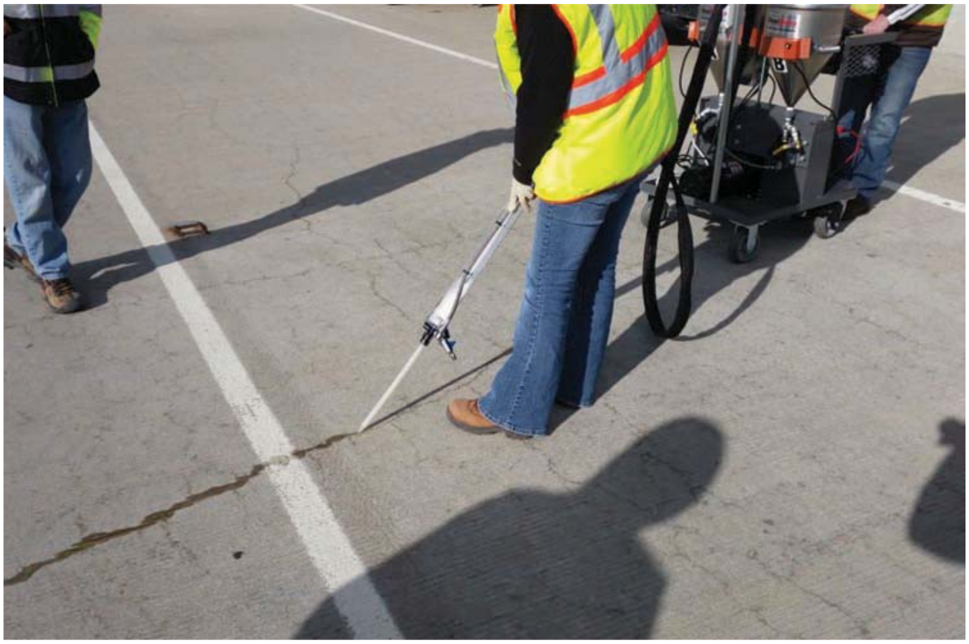


Figure 5.6 Applying Sikadur 55 SLV to a bridge deck crack.

Figure 5.7 Broadcasting sand over the sealed cracks.

No. 231-74-02696 NBL). INDOT developed an apparatus for deck sealer application shown in Figure 5.8. A tank filled with MasterProtect H 400 was placed in the bed of a truck and connected to a sprayer bar mounted to the back of the truck.

During this field test, traffic control was used to restrict traffic to the left of the two lanes. Deck sealer was applied in one pass to cover the right shoulder and a second pass to cover the right lane. The second pass was aligned so that the application areas of each pass overlapped to prevent gaps in the sealer coverage.

5.3.1 Recommendations

Overall, the truck-mounted deck sealer apparatus appeared to be successful in providing consistent sealer coverage across the deck. It is recommended that the deck be cleaned of dust and debris with compressed air prior to sealing. Sandblasting to prepare the deck surface is not required because the deck already has sufficient roughness from surface tining and abrasion. As discussed previously, it is necessary to overlap each successive application pass to ensure full coverage of the deck. Furthermore, it was found that the sprayer

Figure 5.8 Application of MasterProtect H 400 using truck-mounted sprayer bar.

bar should be mounted closer to the pavement to ensure that the proper coverage is achieved.

6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary

Bridge decks deteriorate over time from recurring exposure to deicing salts on roadways during winter. Salt water penetrates the deck at cracks and through the surface of the concrete. The combination of chlorides, water, and oxygen initiate corrosion of the deck reinforcement. Corrosion not only can cause loss of steel section in the reinforcement, but also can cause deterioration of the concrete due to expansive forces, creating the need for periodic deck repairs or deck replacement prior to reaching the expected service life. The objective of this research is to investigate the long-term effectiveness of using crack and deck sealers as a potentially cost-effective method of prolonging the service life of bridge decks by reducing corrosion caused by the intrusion of salt water.

The experimental program was developed and implemented by Lyrenmann (2011) to assess the long-term performance of a select number of crack and deck sealer products applied to a series of 90 macrocell specimens exposed to a salt water ponding regimen. Electrical current in the specimens' reinforcement was measured over 1600 test days to provide continuous monitoring of corrosion activity. A preliminary autopsy completed by Pollastrini (2013) as well as the final autopsy completed in 2016 were used to correlate the collected electrical data with the observed levels of corrosion quantified using two rating methods. Furthermore, a deck sealer was applied to previously unsealed control specimens at an intermediate stage of the program to examine the sealers' capacity to reduce the corrosion rate. Deck sealers were examined further by correlating performance with chloride penetration profiles and sealer penetration depth. Finally, a preliminary field test was completed in 2015 to develop recommendations regarding equipment and methods for field application of sealers.

6.2 Conclusions

The conclusions from the experimental program and preliminary field test are provided below.

6.2.1 Experimental Program

1. Sikadur 55 SLV and Dural 335, low-viscosity epoxies, were shown to be effective in reducing corrosion in cracked concrete by as much as 80 to 100%. The methacrylate crack sealer MasterSeal 630 exhibited contradictory performance. It was found that it has the potential to effectively seal cracks; however, its performance in this experimental program may have been sensitive to installation procedures due to its lower viscosity as compared with the epoxies. Furthermore, methacrylate crack sealers have been shown by Frosch et al. (2010) to be more effective in smaller cracks (< 0.016 in.) than those investigated in this experimental program.
2. The deck sealers MasterProtect H 440 HZ, MasterProtect H 400, and linseed oil were not effective at

preventing salt water intrusion in cracked concrete. Application of a deck surface sealer to cracked concrete resulted in corrosion with severity similar to or exceeding that of unsealed cracked concrete. Furthermore, it was found that application of a deck sealer to cracked concrete (without previous application of a crack sealer) may exacerbate the amount of corrosion in the deck. The use of a deck sealer does not prevent salt water intrusion at cracks; moreover, the deck sealer may actually inhibit evaporation of moisture from the deck, causing even more corrosion than in an unsealed deck.

3. The four crack and deck sealer combinations investigated were extremely successful in reducing chloride ingress and preventing corrosion activity for the duration of the experimental program. The only exception to this performance was the varied results of the sealer combination comprised of crack sealer MasterSeal 630 and deck sealer Master Protect H 440 HZ, which again suggests that MasterSeal 630 may have been sensitive to installation methods.
4. In general, restressing operations to simulate stresses in bridge decks did not negatively affect the performance of the sealers investigated in this study.
5. Deck surface preparation by sandblasting was not found to be beneficial to the performance of crack sealers. It was found that the uniform sandblasting of the entire concrete surface had no influence at the crack locations.
6. The use of a crack and deck sealer combination was shown to effectively supplement the corrosion resistance of epoxy-coated reinforcement in localized areas of coating damage inflicted during transportation and construction. Corrosion, initiated at locations of damaged coating in unsealed specimens, was observed to progress beneath the coating, deteriorating an area much greater than the area visible at the coating defect.
7. Although the use of surface tining was seen to increase chloride penetration depths in unsealed specimens, it was shown that the use of a sealer combination on a tined surface effectively reduced chloride penetration and prevented corrosion activity throughout the duration of the experimental program.
8. Deck sealers MasterProtect H 440 HZ, MasterProtect H 400, and linseed oil applied to surfaces with or without sandblasting for surface preparation were shown to effectively prevent corrosion of reinforcement in uncracked concrete for the duration of the experimental program.
9. Simulation of traffic wear on uncracked concrete with applied deck sealer revealed that the likelihood of corrosion increases as the depth of sealer penetration is abraded over time. Therefore, reapplication of deck sealers over time is warranted.
10. Application of a deck sealer to reinforced concrete with preexisting corrosion did not appear to slow the rate of corrosion. This finding was likely due to the presence of surface cracks, which are not effectively sealed by use of a deck sealer alone. However, given the observed effectiveness of applying both a crack and deck sealer to reduce salt water ingress, it is expected that the use of such a sealer combination would effectively slow the rate of preexisting corrosion.
11. Based on the chloride penetration profiles obtained for the specimens autopsied in 2013 and 2016, deck sealer performance was maintained throughout the duration of the experimental program despite continued exposure to chlorides. Deck sealer performance, however, was diminished by the effects of traffic wear, indicating that reapplication of deck sealers is required over time.

6.2.2 Preliminary Field Test

1. When installing a two-part epoxy crack sealer, such as Sikadur 55 SLV, the use of a two-component joint sealer pump such as the model used in the field test provides an effective and efficient means of crack sealer application with minimized product waste.
2. Cold air temperatures at the time of sealer application have several detrimental effects on the sealing operation. The sealer curing time is extended, the product must be kept warm prior to installation, and the effectiveness of the sealer may be compromised by the potential for reduced penetration depth.
3. Deck sealer application can be accomplished effectively and efficiently by use of a truck-mounted sprayer bar, such as the one developed for the field test. It is possible to avoid gaps in the applied deck sealer coverage by overlapping applications areas in successive passes of the sealing operation.

6.3 Recommendations

The following recommendations are provided based on the conclusions of the experimental program and preliminary field test.

6.3.1 Product Selection

1. Use of the following crack sealer products is recommended to effectively reduce salt water ingress at the cracks. Larger cracks (> 0.016 in.) should be sealed using epoxy crack sealers (Sikadur 55 SLV or Dural 335), and smaller cracks (< 0.016 in.) should be sealed using a methacrylate crack sealer (MasterSeal 630). This recommendation supports that previously presented in Frosch et al. (2010).
2. Completion of crack sealing operations should be followed by the application of a deck sealer to reduce salt water ingress through the concrete surface. Although all three deck sealers in this experimental program were shown to be effective, it has been noted that the use of MasterProtect H 440 HZ is no longer permitted in the state of Indiana, as discussed in Section 2.5. It should also be noted that MasterProtect H 400 is a water-based product. While this product can be effective for initial application, it is not recommended for reapplication as water-based products repel themselves wherever penetrating deck sealers remain from previous applications.

6.3.2 Field Application

1. Sandblasting prior to application of sealers is not required. First, it was shown that sandblasting did not improve the performance of crack sealers. While surface preparation was found to increase the depth of deck sealer penetration, the tined surface and traffic abrasion on the bridge deck already provide adequate roughness for sealer penetration without the need for the additional time, equipment, and costs associated with sandblasting operations.
2. It is recommended that dust and debris are cleaned from cracks in the bridge deck using compressed air prior to the installation of crack sealers. Similarly, the concrete surface should be cleaned of dust and debris using compressed air prior to deck sealing.

3. Because traffic wear reduces sealer effectiveness, roadways with higher volumes of traffic require more frequent sealer reapplications. Without specific traffic abrasion data for a given bridge deck, it is recommended that decks are resealed every 5 years. Extended time periods may be appropriate for bridges with low traffic volumes. As discussed previously, reapplication of a water-based product (such as MasterProtect H 400) is only effective in locations where the sealer has been removed as water-based products repel themselves wherever traces of the sealer remain from previous applications. For this reason, reapplication using non-water-based sealers is recommended. If a water-based sealer is used, the remaining penetration depth of the previous sealer should be removed through preparation of the surface such as sandblasting to ensure that the full penetration depth of the sealer can be achieved.

6.3.2.1 Crack Sealers

1. The use of a pump similar to the one used in the field test is recommended for installation of crack sealers. This type of pump reduces product waste and allows for effective and efficient installation of the sealers. It allows for continuous sealing across the bridge deck with minimal interruptions, and its use with a self-contained power source eliminates the need for extension cords and a generator. It is critical that the pump setup and cleanup procedures are executed as recommended by the pump manufacturer to prolong the life of the equipment and provide for reliable installation of the material.
2. It is recommended that crack sealing operations are completed in air temperatures greater than 60° F to ensure the operation will effectively seal the cracks and not be compromised by the potential inability of the sealer to penetrate the cracks in cold temperatures. Furthermore, additional installation steps are required in cold weather, which reduces the efficiency of the sealing operation.
3. Crack sealer should completely fill the cracks until product refusal to ensure proper sealing of the crack.
4. If a deck is reopened to traffic before cure of the sealer, the freshly sealed cracks should be covered with sand to prevent cars from picking up the material.

6.3.2.2 Deck Sealers

1. A deck sealer application system similar to that developed for the field test is recommended to provide uniform surface coverage.
2. It is recommended that the sprayer bar of the deck sealer application apparatus be fixed at a height close enough to the deck to ensure proper coverage.
3. Deck sealers should be applied using the appropriate coverage rates and number of application coats recommended by the sealer manufacturer.
4. The application areas of each successive pass of sealer application should overlap to avoid gaps in deck sealer coverage.

6.4 Future Research

It is recommended that future research investigate the effectiveness of deck sealers in cracked concrete when cracks are first flooded to product refusal prior to application of the recommended surface coverage rate. Cracked specimens in this study that were treated with deck sealers were only sealed with the recommended surface coverage. It would be valuable to ascertain whether a crack flooded with deck sealer will resist salt water intrusion in a manner similar to that of a crack treated with an epoxy or methacrylate crack sealer. If the use of a deck sealer to flood cracks and coat the deck were as effective as the application of a crack and deck sealer combination, it would reduce costs associated with time, equipment, and personnel required to complete the sealing operation.

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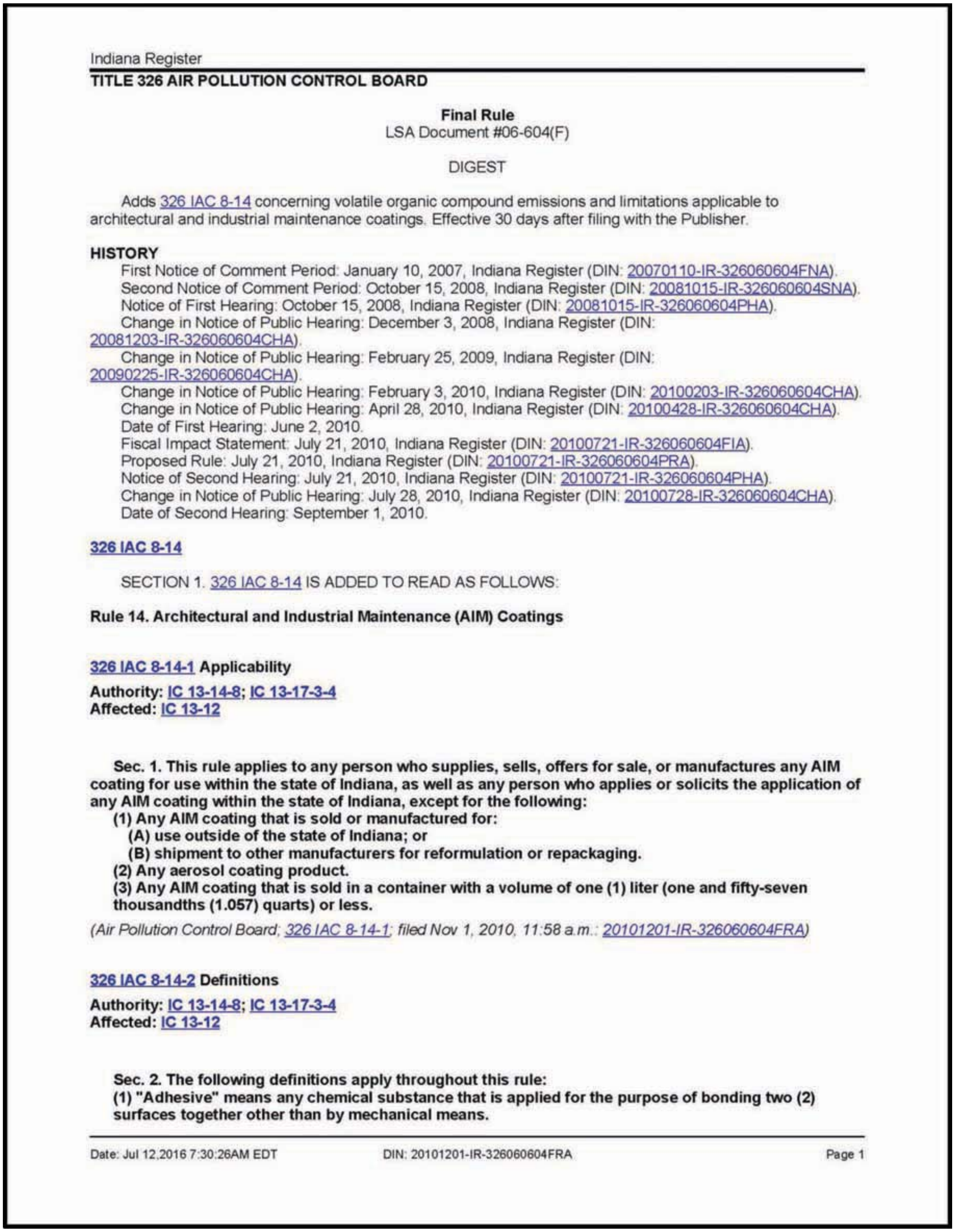
APPENDICES

APPENDIX A. CHANGE IN VOLATILE ORGANIC COMPOUND (VOC) LIMIT

The Final Rule, LSA Document #06-604(F) is presented in Figure A.1. This document implements changes to the volatile organic compound (VOC) limit for waterproofing concrete or masonry sealers.



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TITLE 326 AIR POLLUTION CONTROL BOARD

Final Rule
LSA Document #06-604(F)

DIGEST

Adds 326 IAC 8-14 concerning volatile organic compound emissions and limitations applicable to architectural and industrial maintenance coatings. Effective 30 days after filing with the Publisher.

HISTORY

First Notice of Comment Period: January 10, 2007, Indiana Register (DIN: 20070110-IR-326060604FNA).
Second Notice of Comment Period: October 15, 2008, Indiana Register (DIN: 20081015-IR-326060604SNA).
Notice of First Hearing: October 15, 2008, Indiana Register (DIN: 20081015-IR-326060604PHA).
Change in Notice of Public Hearing: December 3, 2008, Indiana Register (DIN: 20081203-IR-326060604CHA).
Change in Notice of Public Hearing: February 25, 2009, Indiana Register (DIN: 20090225-IR-326060604CHA).
Change in Notice of Public Hearing: February 3, 2010, Indiana Register (DIN: 20100203-IR-326060604CHA).
Change in Notice of Public Hearing: April 28, 2010, Indiana Register (DIN: 20100428-IR-326060604CHA).
Date of First Hearing: June 2, 2010.
Fiscal Impact Statement: July 21, 2010, Indiana Register (DIN: 20100721-IR-326060604FIA).
Proposed Rule: July 21, 2010, Indiana Register (DIN: 20100721-IR-326060604PRA).
Notice of Second Hearing: July 21, 2010, Indiana Register (DIN: 20100721-IR-326060604PHA).
Change in Notice of Public Hearing: July 28, 2010, Indiana Register (DIN: 20100728-IR-326060604CHA).
Date of Second Hearing: September 1, 2010.

326 IAC 8-14

SECTION 1. 326 IAC 8-14 IS ADDED TO READ AS FOLLOWS:

Rule 14. Architectural and Industrial Maintenance (AIM) Coatings

326 IAC 8-14-1 Applicability

Authority: IC 13-14-8; IC 13-17-3-4
Affected: IC 13-12

Sec. 1. This rule applies to any person who supplies, sells, offers for sale, or manufactures any AIM coating for use within the state of Indiana, as well as any person who applies or solicits the application of any AIM coating within the state of Indiana, except for the following:
(1) Any AIM coating that is sold or manufactured for:
  (A) use outside of the state of Indiana; or
  (B) shipment to other manufacturers for reformulation or repackaging.
(2) Any aerosol coating product.
(3) Any AIM coating that is sold in a container with a volume of one (1) liter (one and fifty-seven thousandths (1.057) quarts) or less.

(Air Pollution Control Board; 326 IAC 8-14-1; filed Nov 1, 2010, 11:58 a.m.: 20101201-IR-326060604FRA)

326 IAC 8-14-2 Definitions

Authority: IC 13-14-8; IC 13-17-3-4
Affected: IC 13-12

Sec. 2. The following definitions apply throughout this rule:
(1) "Adhesive" means any chemical substance that is applied for the purpose of bonding two (2) surfaces together other than by mechanical means.

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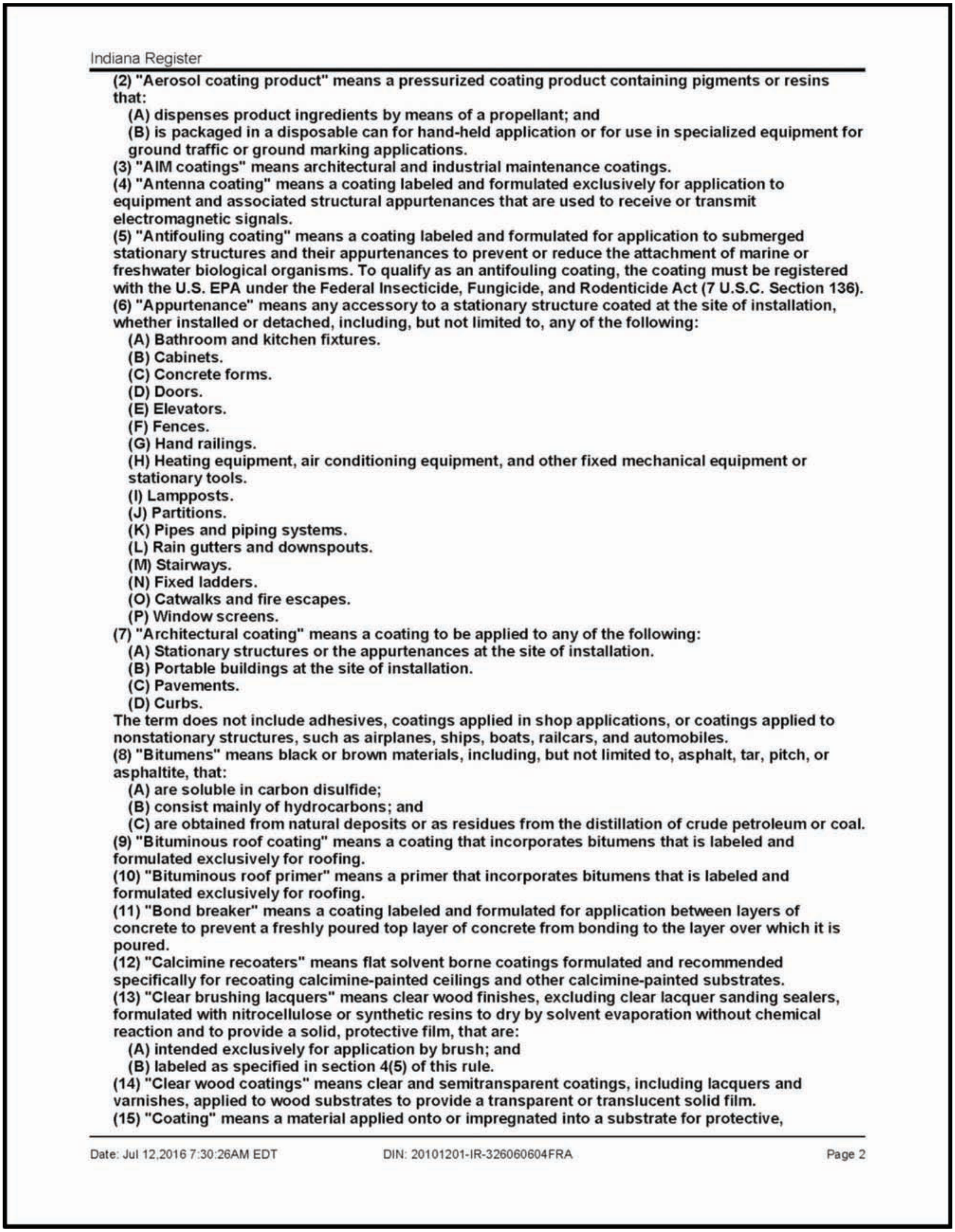
Figure A.1 Final rule for volatile organic compound (VOC) limit.



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(2) "Aerosol coating product" means a pressurized coating product containing pigments or resins that:
- **(A) dispenses product ingredients by means of a propellant; and**
- **(B) is packaged in a disposable can for hand-held application or for use in specialized equipment for ground traffic or ground marking applications.**

(3) "AIM coatings" means architectural and industrial maintenance coatings.

(4) "Antenna coating" means a coating labeled and formulated exclusively for application to equipment and associated structural appurtenances that are used to receive or transmit electromagnetic signals.

(5) "Antifouling coating" means a coating labeled and formulated for application to submerged stationary structures and their appurtenances to prevent or reduce the attachment of marine or freshwater biological organisms. To qualify as an antifouling coating, the coating must be registered with the U.S. EPA under the Federal Insecticide, Fungicide, and Rodenticide Act (7 U.S.C. Section 136).

(6) "Appurtenance" means any accessory to a stationary structure coated at the site of installation, whether installed or detached, including, but not limited to, any of the following:
- **(A) Bathroom and kitchen fixtures.**
- **(B) Cabinets.**
- **(C) Concrete forms.**
- **(D) Doors.**
- **(E) Elevators.**
- **(F) Fences.**
- **(G) Hand railings.**
- **(H) Heating equipment, air conditioning equipment, and other fixed mechanical equipment or stationary tools.**
- **(I) Lampposts.**
- **(J) Partitions.**
- **(K) Pipes and piping systems.**
- **(L) Rain gutters and downspouts.**
- **(M) Stairways.**
- **(N) Fixed ladders.**
- **(O) Catwalks and fire escapes.**
- **(P) Window screens.**

(7) "Architectural coating" means a coating to be applied to any of the following:
- **(A) Stationary structures or the appurtenances at the site of installation.**
- **(B) Portable buildings at the site of installation.**
- **(C) Pavements.**
- **(D) Curbs.**

The term does not include adhesives, coatings applied in shop applications, or coatings applied to nonstationary structures, such as airplanes, ships, boats, railcars, and automobiles.

(8) "Bitumens" means black or brown materials, including, but not limited to, asphalt, tar, pitch, or asphaltite, that:
- **(A) are soluble in carbon disulfide;**
- **(B) consist mainly of hydrocarbons; and**
- **(C) are obtained from natural deposits or as residues from the distillation of crude petroleum or coal.**

(9) "Bituminous roof coating" means a coating that incorporates bitumens that is labeled and formulated exclusively for roofing.

(10) "Bituminous roof primer" means a primer that incorporates bitumens that is labeled and formulated exclusively for roofing.

(11) "Bond breaker" means a coating labeled and formulated for application between layers of concrete to prevent a freshly poured top layer of concrete from bonding to the layer over which it is poured.

(12) "Calcimine recoaters" means flat solvent borne coatings formulated and recommended specifically for recoating calcimine-painted ceilings and other calcimine-painted substrates.

(13) "Clear brushing lacquers" means clear wood finishes, excluding clear lacquer sanding sealers, formulated with nitrocellulose or synthetic resins to dry by solvent evaporation without chemical reaction and to provide a solid, protective film, that are:
- **(A) intended exclusively for application by brush; and**
- **(B) labeled as specified in section 4(5) of this rule.**

(14) "Clear wood coatings" means clear and semitransparent coatings, including lacquers and varnishes, applied to wood substrates to provide a transparent or translucent solid film.

(15) "Coating" means a material applied onto or impregnated into a substrate for protective,

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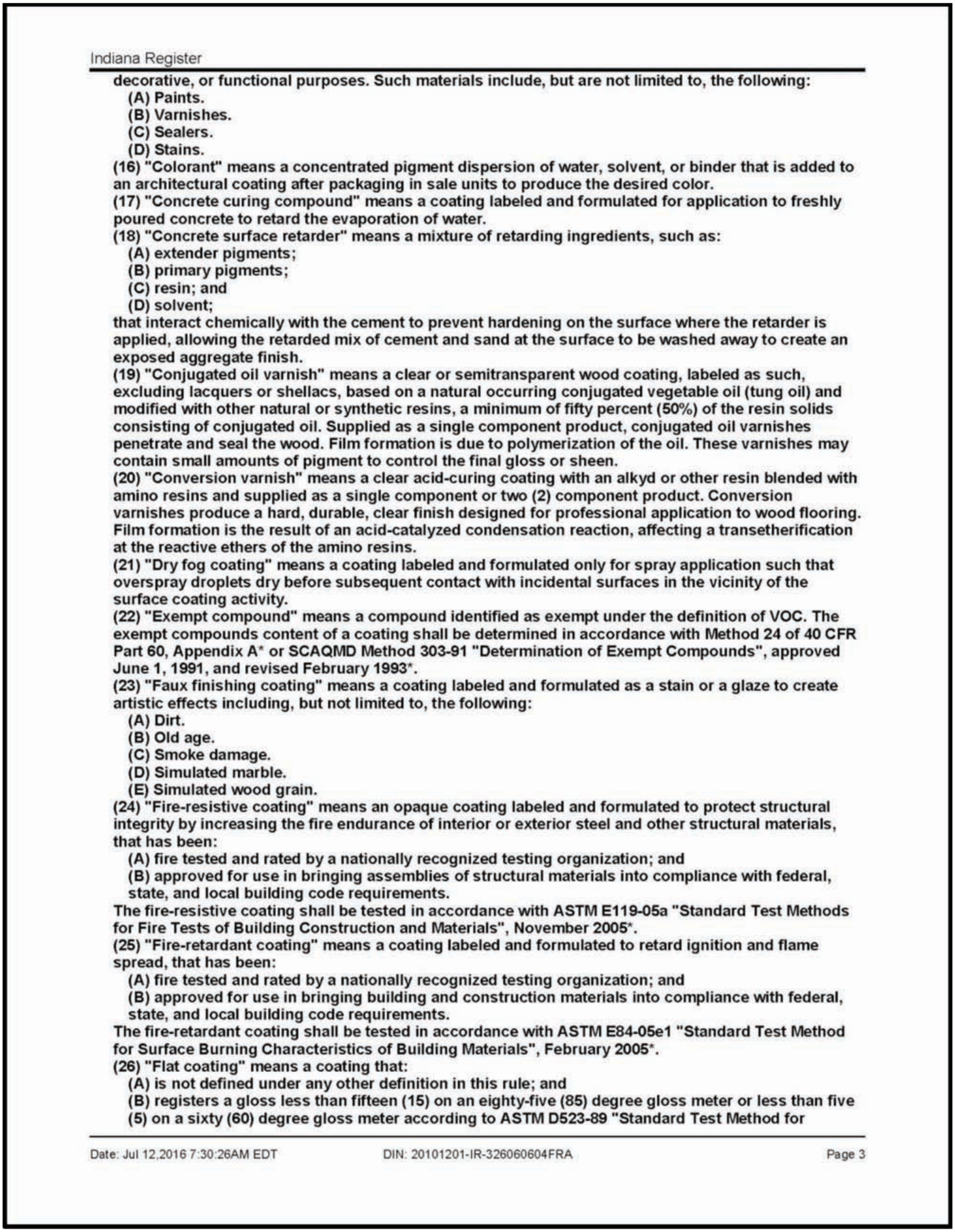
Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



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decorative, or functional purposes. Such materials include, but are not limited to, the following:
  (A) Paints.
  (B) Varnishes.
  (C) Sealers.
  (D) Stains.

(16) "Colorant" means a concentrated pigment dispersion of water, solvent, or binder that is added to an architectural coating after packaging in sale units to produce the desired color.

(17) "Concrete curing compound" means a coating labeled and formulated for application to freshly poured concrete to retard the evaporation of water.

(18) "Concrete surface retarder" means a mixture of retarding ingredients, such as:
  (A) extender pigments;
  (B) primary pigments;
  (C) resin; and
  (D) solvent;

that interact chemically with the cement to prevent hardening on the surface where the retarder is applied, allowing the retarded mix of cement and sand at the surface to be washed away to create an exposed aggregate finish.

(19) "Conjugated oil varnish" means a clear or semitransparent wood coating, labeled as such, excluding lacquers or shellacs, based on a natural occurring conjugated vegetable oil (tung oil) and modified with other natural or synthetic resins, a minimum of fifty percent (50%) of the resin solids consisting of conjugated oil. Supplied as a single component product, conjugated oil varnishes penetrate and seal the wood. Film formation is due to polymerization of the oil. These varnishes may contain small amounts of pigment to control the final gloss or sheen.

(20) "Conversion varnish" means a clear acid-curing coating with an alkyd or other resin blended with amino resins and supplied as a single component or two (2) component product. Conversion varnishes produce a hard, durable, clear finish designed for professional application to wood flooring. Film formation is the result of an acid-catalyzed condensation reaction, affecting a transetherification at the reactive ethers of the amino resins.

(21) "Dry fog coating" means a coating labeled and formulated only for spray application such that overspray droplets dry before subsequent contact with incidental surfaces in the vicinity of the surface coating activity.

(22) "Exempt compound" means a compound identified as exempt under the definition of VOC. The exempt compounds content of a coating shall be determined in accordance with Method 24 of 40 CFR Part 60, Appendix A* or SCAQMD Method 303-91 "Determination of Exempt Compounds", approved June 1, 1991, and revised February 1993*.

(23) "Faux finishing coating" means a coating labeled and formulated as a stain or a glaze to create artistic effects including, but not limited to, the following:
  (A) Dirt.
  (B) Old age.
  (C) Smoke damage.
  (D) Simulated marble.
  (E) Simulated wood grain.

(24) "Fire-resistive coating" means an opaque coating labeled and formulated to protect structural integrity by increasing the fire endurance of interior or exterior steel and other structural materials, that has been:
  (A) fire tested and rated by a nationally recognized testing organization; and
  (B) approved for use in bringing assemblies of structural materials into compliance with federal, state, and local building code requirements.

The fire-resistive coating shall be tested in accordance with ASTM E119-05a "Standard Test Methods for Fire Tests of Building Construction and Materials", November 2005*.

(25) "Fire-retardant coating" means a coating labeled and formulated to retard ignition and flame spread, that has been:
  (A) fire tested and rated by a nationally recognized testing organization; and
  (B) approved for use in bringing building and construction materials into compliance with federal, state, and local building code requirements.

The fire-retardant coating shall be tested in accordance with ASTM E84-05e1 "Standard Test Method for Surface Burning Characteristics of Building Materials", February 2005*.

(26) "Flat coating" means a coating that:
  (A) is not defined under any other definition in this rule; and
  (B) registers a gloss less than fifteen (15) on an eighty-five (85) degree gloss meter or less than five (5) on a sixty (60) degree gloss meter according to ASTM D523-89 "Standard Test Method for

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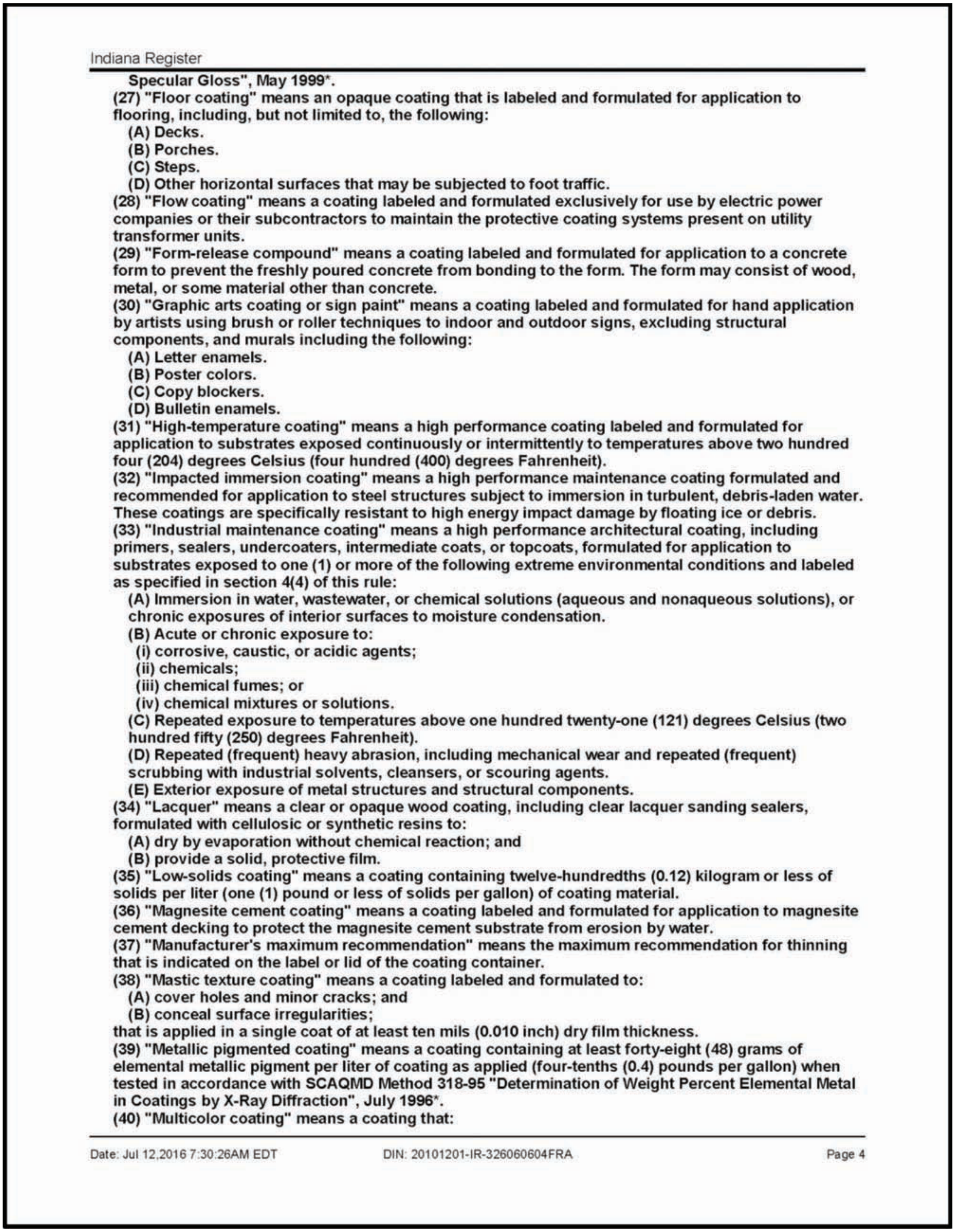
Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



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Specular Gloss", May 1999*.

(27) "Floor coating" means an opaque coating that is labeled and formulated for application to flooring, including, but not limited to, the following:

(A) Decks.
(B) Porches.
(C) Steps.
(D) Other horizontal surfaces that may be subjected to foot traffic.

(28) "Flow coating" means a coating labeled and formulated exclusively for use by electric power companies or their subcontractors to maintain the protective coating systems present on utility transformer units.

(29) "Form-release compound" means a coating labeled and formulated for application to a concrete form to prevent the freshly poured concrete from bonding to the form. The form may consist of wood, metal, or some material other than concrete.

(30) "Graphic arts coating or sign paint" means a coating labeled and formulated for hand application by artists using brush or roller techniques to indoor and outdoor signs, excluding structural components, and murals including the following:

(A) Letter enamels.
(B) Poster colors.
(C) Copy blockers.
(D) Bulletin enamels.

(31) "High-temperature coating" means a high performance coating labeled and formulated for application to substrates exposed continuously or intermittently to temperatures above two hundred four (204) degrees Celsius (four hundred (400) degrees Fahrenheit).

(32) "Impacted immersion coating" means a high performance maintenance coating formulated and recommended for application to steel structures subject to immersion in turbulent, debris-laden water. These coatings are specifically resistant to high energy impact damage by floating ice or debris.

(33) "Industrial maintenance coating" means a high performance architectural coating, including primers, sealers, undercoaters, intermediate coats, or topcoats, formulated for application to substrates exposed to one (1) or more of the following extreme environmental conditions and labeled as specified in section 4(4) of this rule:

(A) Immersion in water, wastewater, or chemical solutions (aqueous and nonaqueous solutions), or chronic exposures of interior surfaces to moisture condensation.
(B) Acute or chronic exposure to:
  (i) corrosive, caustic, or acidic agents;
  (ii) chemicals;
  (iii) chemical fumes; or
  (iv) chemical mixtures or solutions.
(C) Repeated exposure to temperatures above one hundred twenty-one (121) degrees Celsius (two hundred fifty (250) degrees Fahrenheit).
(D) Repeated (frequent) heavy abrasion, including mechanical wear and repeated (frequent) scrubbing with industrial solvents, cleansers, or scouring agents.
(E) Exterior exposure of metal structures and structural components.

(34) "Lacquer" means a clear or opaque wood coating, including clear lacquer sanding sealers, formulated with cellulosic or synthetic resins to:

(A) dry by evaporation without chemical reaction; and
(B) provide a solid, protective film.

(35) "Low-solids coating" means a coating containing twelve-hundredths (0.12) kilogram or less of solids per liter (one (1) pound or less of solids per gallon) of coating material.

(36) "Magnesite cement coating" means a coating labeled and formulated for application to magnesite cement decking to protect the magnesite cement substrate from erosion by water.

(37) "Manufacturer's maximum recommendation" means the maximum recommendation for thinning that is indicated on the label or lid of the coating container.

(38) "Mastic texture coating" means a coating labeled and formulated to:

(A) cover holes and minor cracks; and
(B) conceal surface irregularities;

that is applied in a single coat of at least ten mils (0.010 inch) dry film thickness.

(39) "Metallic pigmented coating" means a coating containing at least forty-eight (48) grams of elemental metallic pigment per liter of coating as applied (four-tenths (0.4) pounds per gallon) when tested in accordance with SCAQMD Method 318-95 "Determination of Weight Percent Elemental Metal in Coatings by X-Ray Diffraction", July 1996*.

(40) "Multicolor coating" means a coating that:

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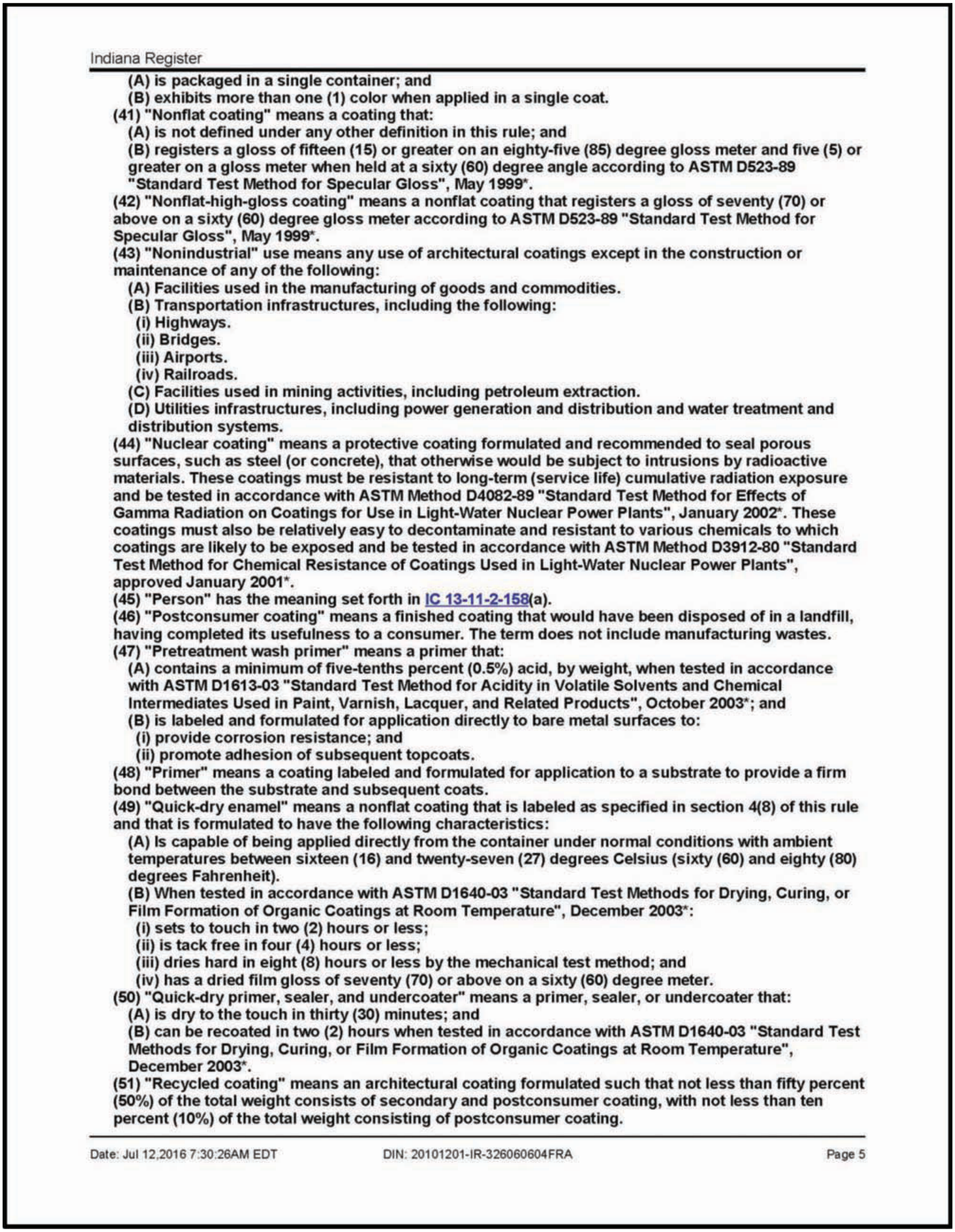
Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



(A) is packaged in a single container; and
(B) exhibits more than one (1) color when applied in a single coat.

(41) "Nonflat coating" means a coating that:
(A) is not defined under any other definition in this rule; and
(B) registers a gloss of fifteen (15) or greater on an eighty-five (85) degree gloss meter and five (5) or greater on a gloss meter when held at a sixty (60) degree angle according to ASTM D523-89 "Standard Test Method for Specular Gloss", May 1999*.

(42) "Nonflat-high-gloss coating" means a nonflat coating that registers a gloss of seventy (70) or above on a sixty (60) degree gloss meter according to ASTM D523-89 "Standard Test Method for Specular Gloss", May 1999*.

(43) "Nonindustrial" use means any use of architectural coatings except in the construction or maintenance of any of the following:
(A) Facilities used in the manufacturing of goods and commodities.
(B) Transportation infrastructures, including the following:
(i) Highways.
(ii) Bridges.
(iii) Airports.
(iv) Railroads.
(C) Facilities used in mining activities, including petroleum extraction.
(D) Utilities infrastructures, including power generation and distribution and water treatment and distribution systems.

(44) "Nuclear coating" means a protective coating formulated and recommended to seal porous surfaces, such as steel (or concrete), that otherwise would be subject to intrusions by radioactive materials. These coatings must be resistant to long-term (service life) cumulative radiation exposure and be tested in accordance with ASTM Method D4082-89 "Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light-Water Nuclear Power Plants", January 2002*. These coatings must also be relatively easy to decontaminate and resistant to various chemicals to which coatings are likely to be exposed and be tested in accordance with ASTM Method D3912-80 "Standard Test Method for Chemical Resistance of Coatings Used in Light-Water Nuclear Power Plants", approved January 2001*.

(45) "Person" has the meaning set forth in IC 13-11-2-158(a).

(46) "Postconsumer coating" means a finished coating that would have been disposed of in a landfill, having completed its usefulness to a consumer. The term does not include manufacturing wastes.

(47) "Pretreatment wash primer" means a primer that:
(A) contains a minimum of five-tenths percent (0.5%) acid, by weight, when tested in accordance with ASTM D1613-03 "Standard Test Method for Acidity in Volatile Solvents and Chemical Intermediates Used in Paint, Varnish, Lacquer, and Related Products", October 2003*; and
(B) is labeled and formulated for application directly to bare metal surfaces to:
(i) provide corrosion resistance; and
(ii) promote adhesion of subsequent topcoats.

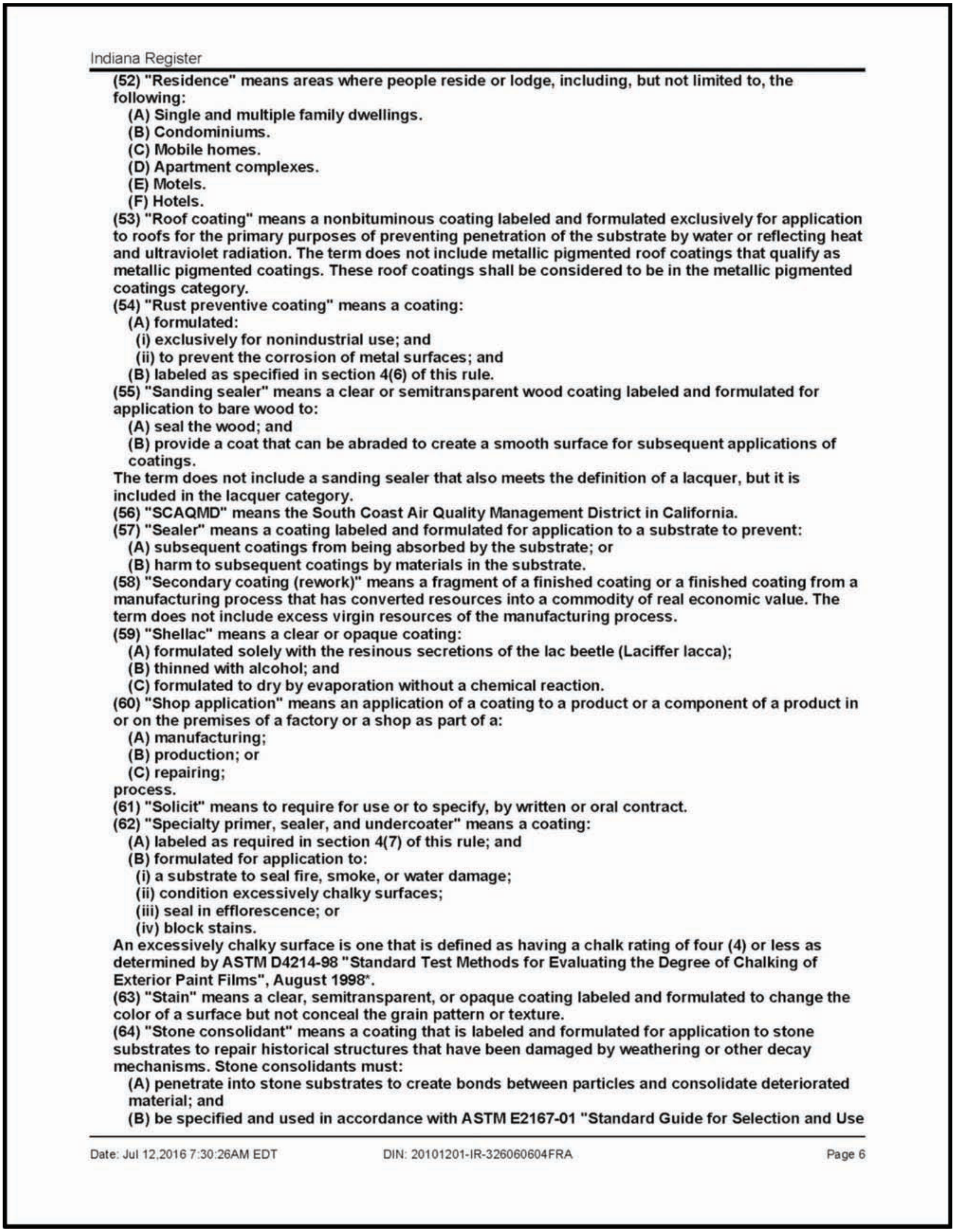
(48) "Primer" means a coating labeled and formulated for application to a substrate to provide a firm bond between the substrate and subsequent coats.

(49) "Quick-dry enamel" means a nonflat coating that is labeled as specified in section 4(8) of this rule and that is formulated to have the following characteristics:
(A) Is capable of being applied directly from the container under normal conditions with ambient temperatures between sixteen (16) and twenty-seven (27) degrees Celsius (sixty (60) and eighty (80) degrees Fahrenheit).
(B) When tested in accordance with ASTM D1640-03 "Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings at Room Temperature", December 2003*:
(i) sets to touch in two (2) hours or less;
(ii) is tack free in four (4) hours or less;
(iii) dries hard in eight (8) hours or less by the mechanical test method; and
(iv) has a dried film gloss of seventy (70) or above on a sixty (60) degree meter.

(50) "Quick-dry primer, sealer, and undercoater" means a primer, sealer, or undercoater that:
(A) is dry to the touch in thirty (30) minutes; and
(B) can be recoated in two (2) hours when tested in accordance with ASTM D1640-03 "Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings at Room Temperature", December 2003*.

(51) "Recycled coating" means an architectural coating formulated such that not less than fifty percent (50%) of the total weight consists of secondary and postconsumer coating, with not less than ten percent (10%) of the total weight consisting of postconsumer coating.

Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



(52) "Residence" means areas where people reside or lodge, including, but not limited to, the following:
- (A) Single and multiple family dwellings.
- (B) Condominiums.
- (C) Mobile homes.
- (D) Apartment complexes.
- (E) Motels.
- (F) Hotels.

(53) "Roof coating" means a nonbituminous coating labeled and formulated exclusively for application to roofs for the primary purposes of preventing penetration of the substrate by water or reflecting heat and ultraviolet radiation. The term does not include metallic pigmented roof coatings that qualify as metallic pigmented coatings. These roof coatings shall be considered to be in the metallic pigmented coatings category.

(54) "Rust preventive coating" means a coating:
- (A) formulated:
  - (i) exclusively for nonindustrial use; and
  - (ii) to prevent the corrosion of metal surfaces; and
- (B) labeled as specified in section 4(6) of this rule.

(55) "Sanding sealer" means a clear or semitransparent wood coating labeled and formulated for application to bare wood to:
- (A) seal the wood; and
- (B) provide a coat that can be abraded to create a smooth surface for subsequent applications of coatings.

The term does not include a sanding sealer that also meets the definition of a lacquer, but it is included in the lacquer category.

(56) "SCAQMD" means the South Coast Air Quality Management District in California.

(57) "Sealer" means a coating labeled and formulated for application to a substrate to prevent:
- (A) subsequent coatings from being absorbed by the substrate; or
- (B) harm to subsequent coatings by materials in the substrate.

(58) "Secondary coating (rework)" means a fragment of a finished coating or a finished coating from a manufacturing process that has converted resources into a commodity of real economic value. The term does not include excess virgin resources of the manufacturing process.

(59) "Shellac" means a clear or opaque coating:
- (A) formulated solely with the resinous secretions of the lac beetle (Laciffer lacca);
- (B) thinned with alcohol; and
- (C) formulated to dry by evaporation without a chemical reaction.

(60) "Shop application" means an application of a coating to a product or a component of a product in or on the premises of a factory or a shop as part of a:
- (A) manufacturing;
- (B) production; or
- (C) repairing;

process.

(61) "Solicit" means to require for use or to specify, by written or oral contract.

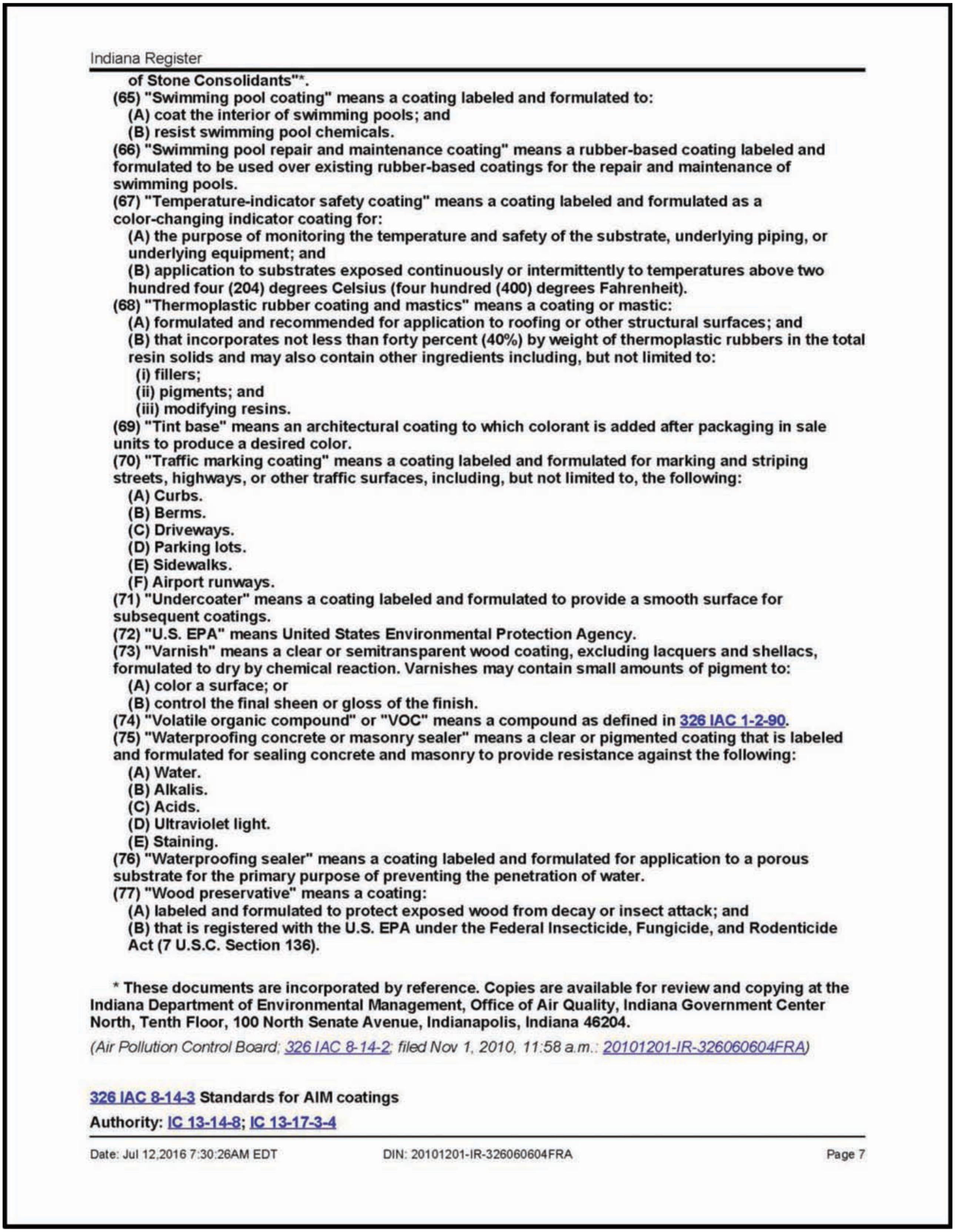
(62) "Specialty primer, sealer, and undercoater" means a coating:
- (A) labeled as required in section 4(7) of this rule; and
- (B) formulated for application to:
  - (i) a substrate to seal fire, smoke, or water damage;
  - (ii) condition excessively chalky surfaces;
  - (iii) seal in efflorescence; or
  - (iv) block stains.

An excessively chalky surface is one that is defined as having a chalk rating of four (4) or less as determined by ASTM D4214-98 "Standard Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films", August 1998*.

(63) "Stain" means a clear, semitransparent, or opaque coating labeled and formulated to change the color of a surface but not conceal the grain pattern or texture.

(64) "Stone consolidant" means a coating that is labeled and formulated for application to stone substrates to repair historical structures that have been damaged by weathering or other decay mechanisms. Stone consolidants must:
- (A) penetrate into stone substrates to create bonds between particles and consolidate deteriorated material; and
- (B) be specified and used in accordance with ASTM E2167-01 "Standard Guide for Selection and Use

Figure A.1 **(cont.)** Final rule for volatile organic compound (VOC) limit.



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of Stone Consolidants"*.

(65) "Swimming pool coating" means a coating labeled and formulated to:
- **(A) coat the interior of swimming pools; and**
- **(B) resist swimming pool chemicals.**

(66) "Swimming pool repair and maintenance coating" means a rubber-based coating labeled and formulated to be used over existing rubber-based coatings for the repair and maintenance of swimming pools.

(67) "Temperature-indicator safety coating" means a coating labeled and formulated as a color-changing indicator coating for:
- **(A) the purpose of monitoring the temperature and safety of the substrate, underlying piping, or underlying equipment; and**
- **(B) application to substrates exposed continuously or intermittently to temperatures above two hundred four (204) degrees Celsius (four hundred (400) degrees Fahrenheit).**

(68) "Thermoplastic rubber coating and mastics" means a coating or mastic:
- **(A) formulated and recommended for application to roofing or other structural surfaces; and**
- **(B) that incorporates not less than forty percent (40%) by weight of thermoplastic rubbers in the total resin solids and may also contain other ingredients including, but not limited to:**
  - **(i) fillers;**
  - **(ii) pigments; and**
  - **(iii) modifying resins.**

(69) "Tint base" means an architectural coating to which colorant is added after packaging in sale units to produce a desired color.

(70) "Traffic marking coating" means a coating labeled and formulated for marking and striping streets, highways, or other traffic surfaces, including, but not limited to, the following:
- **(A) Curbs.**
- **(B) Berms.**
- **(C) Driveways.**
- **(D) Parking lots.**
- **(E) Sidewalks.**
- **(F) Airport runways.**

(71) "Undercoater" means a coating labeled and formulated to provide a smooth surface for subsequent coatings.

(72) "U.S. EPA" means United States Environmental Protection Agency.

(73) "Varnish" means a clear or semitransparent wood coating, excluding lacquers and shellacs, formulated to dry by chemical reaction. Varnishes may contain small amounts of pigment to:
- **(A) color a surface; or**
- **(B) control the final sheen or gloss of the finish.**

(74) "Volatile organic compound" or "VOC" means a compound as defined in 326 IAC 1-2-90.

(75) "Waterproofing concrete or masonry sealer" means a clear or pigmented coating that is labeled and formulated for sealing concrete and masonry to provide resistance against the following:
- **(A) Water.**
- **(B) Alkalis.**
- **(C) Acids.**
- **(D) Ultraviolet light.**
- **(E) Staining.**

(76) "Waterproofing sealer" means a coating labeled and formulated for application to a porous substrate for the primary purpose of preventing the penetration of water.

(77) "Wood preservative" means a coating:
- **(A) labeled and formulated to protect exposed wood from decay or insect attack; and**
- **(B) that is registered with the U.S. EPA under the Federal Insecticide, Fungicide, and Rodenticide Act (7 U.S.C. Section 136).**

*** These documents are incorporated by reference. Copies are available for review and copying at the Indiana Department of Environmental Management, Office of Air Quality, Indiana Government Center North, Tenth Floor, 100 North Senate Avenue, Indianapolis, Indiana 46204.**

(Air Pollution Control Board; 326 IAC 8-14-2; filed Nov 1, 2010, 11:58 a.m.: 20101201-IR-326060604FRA)

326 IAC 8-14-3 Standards for AIM coatings

Authority: IC 13-14-8; IC 13-17-3-4

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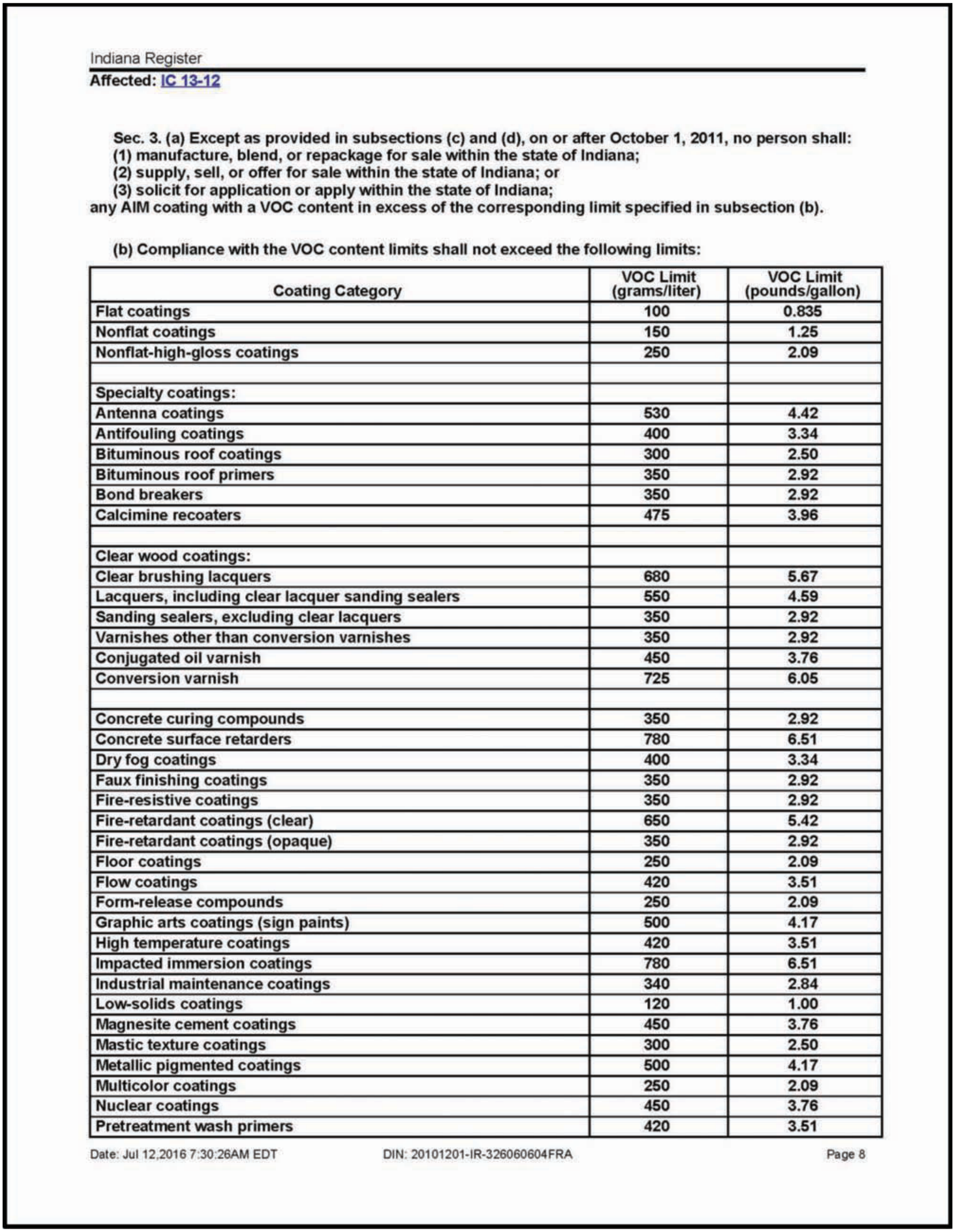
Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



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Affected: IC 13-12

Sec. 3. (a) Except as provided in subsections (c) and (d), on or after October 1, 2011, no person shall:

(1) manufacture, blend, or repackage for sale within the state of Indiana;

(2) supply, sell, or offer for sale within the state of Indiana; or

(3) solicit for application or apply within the state of Indiana;

any AIM coating with a VOC content in excess of the corresponding limit specified in subsection (b).

(b) Compliance with the VOC content limits shall not exceed the following limits:

Coating Category	VOC Limit (grams/liter)	VOC Limit (pounds/gallon)
Flat coatings	100	0.835
Nonflat coatings	150	1.25
Nonflat-high-gloss coatings	250	2.09
Specialty coatings:		
Antenna coatings	530	4.42
Antifouling coatings	400	3.34
Bituminous roof coatings	300	2.50
Bituminous roof primers	350	2.92
Bond breakers	350	2.92
Calcimine recoaters	475	3.96
Clear wood coatings:		
Clear brushing lacquers	680	5.67
Lacquers, including clear lacquer sanding sealers	550	4.59
Sanding sealers, excluding clear lacquers	350	2.92
Varnishes other than conversion varnishes	350	2.92
Conjugated oil varnish	450	3.76
Conversion varnish	725	6.05
Concrete curing compounds	350	2.92
Concrete surface retarders	780	6.51
Dry fog coatings	400	3.34
Faux finishing coatings	350	2.92
Fire-resistive coatings	350	2.92
Fire-retardant coatings (clear)	650	5.42
Fire-retardant coatings (opaque)	350	2.92
Floor coatings	250	2.09
Flow coatings	420	3.51
Form-release compounds	250	2.09
Graphic arts coatings (sign paints)	500	4.17
High temperature coatings	420	3.51
Impacted immersion coatings	780	6.51
Industrial maintenance coatings	340	2.84
Low-solids coatings	120	1.00
Magnesite cement coatings	450	3.76
Mastic texture coatings	300	2.50
Metallic pigmented coatings	500	4.17
Multicolor coatings	250	2.09
Nuclear coatings	450	3.76
Pretreatment wash primers	420	3.51

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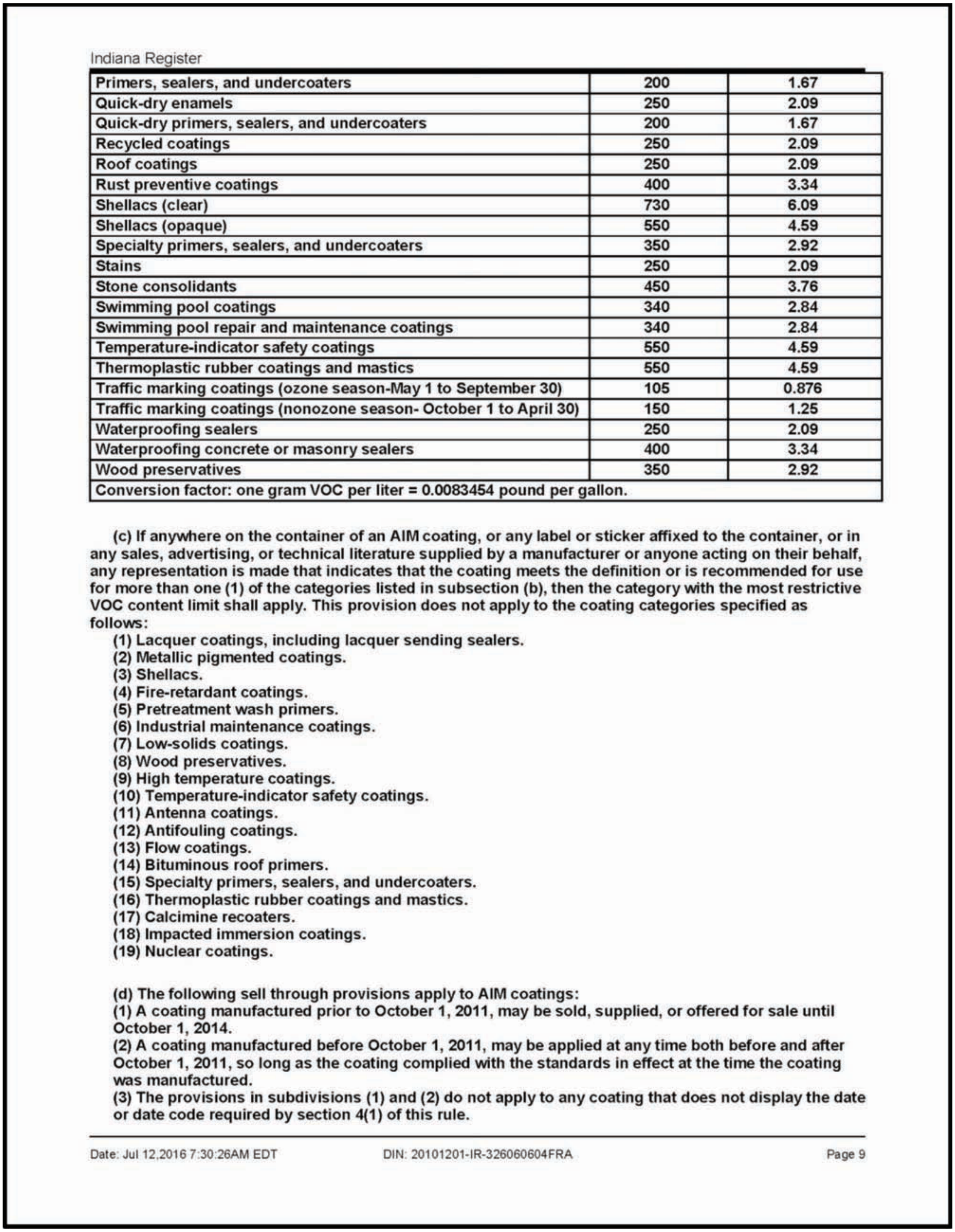
Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



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Primers, sealers, and undercoaters	200	1.67
Quick-dry enamels	250	2.09
Quick-dry primers, sealers, and undercoaters	200	1.67
Recycled coatings	250	2.09
Roof coatings	250	2.09
Rust preventive coatings	400	3.34
Shellacs (clear)	730	6.09
Shellacs (opaque)	550	4.59
Specialty primers, sealers, and undercoaters	350	2.92
Stains	250	2.09
Stone consolidants	450	3.76
Swimming pool coatings	340	2.84
Swimming pool repair and maintenance coatings	340	2.84
Temperature-indicator safety coatings	550	4.59
Thermoplastic rubber coatings and mastics	550	4.59
Traffic marking coatings (ozone season-May 1 to September 30)	105	0.876
Traffic marking coatings (nonozone season- October 1 to April 30)	150	1.25
Waterproofing sealers	250	2.09
Waterproofing concrete or masonry sealers	400	3.34
Wood preservatives	350	2.92
Conversion factor: one gram VOC per liter = 0.0083454 pound per gallon.		

(c) If anywhere on the container of an AIM coating, or any label or sticker affixed to the container, or in any sales, advertising, or technical literature supplied by a manufacturer or anyone acting on their behalf, any representation is made that indicates that the coating meets the definition or is recommended for use for more than one (1) of the categories listed in subsection (b), then the category with the most restrictive VOC content limit shall apply. This provision does not apply to the coating categories specified as follows:

(1) Lacquer coatings, including lacquer sending sealers.
(2) Metallic pigmented coatings.
(3) Shellacs.
(4) Fire-retardant coatings.
(5) Pretreatment wash primers.
(6) Industrial maintenance coatings.
(7) Low-solids coatings.
(8) Wood preservatives.
(9) High temperature coatings.
(10) Temperature-indicator safety coatings.
(11) Antenna coatings.
(12) Antifouling coatings.
(13) Flow coatings.
(14) Bituminous roof primers.
(15) Specialty primers, sealers, and undercoaters.
(16) Thermoplastic rubber coatings and mastics.
(17) Calcimine recoaters.
(18) Impacted immersion coatings.
(19) Nuclear coatings.

(d) The following sell through provisions apply to AIM coatings:
(1) A coating manufactured prior to October 1, 2011, may be sold, supplied, or offered for sale until October 1, 2014.
(2) A coating manufactured before October 1, 2011, may be applied at any time both before and after October 1, 2011, so long as the coating complied with the standards in effect at the time the coating was manufactured.
(3) The provisions in subdivisions (1) and (2) do not apply to any coating that does not display the date or date code required by section 4(1) of this rule.

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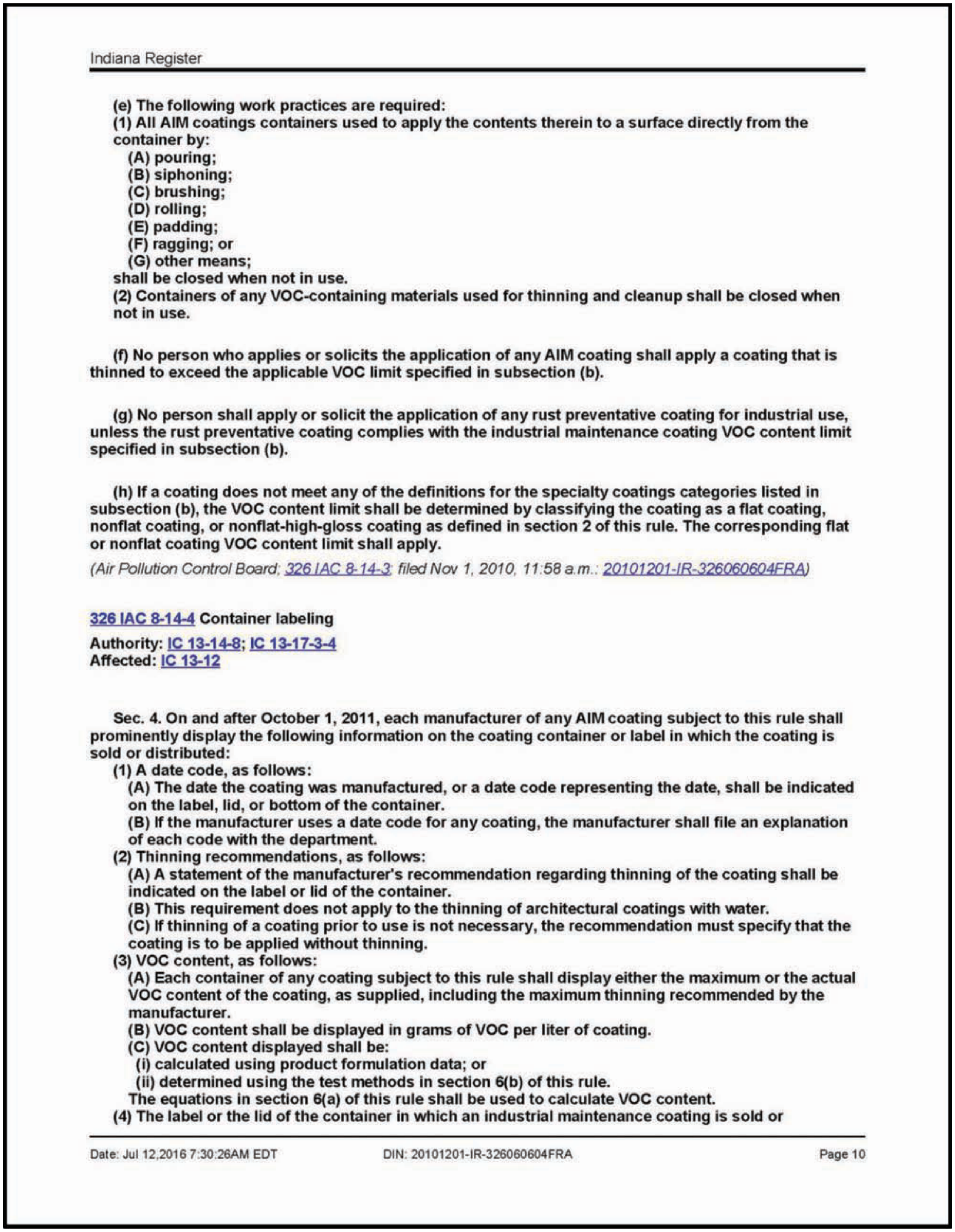
Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



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(e) The following work practices are required:
(1) All AIM coatings containers used to apply the contents therein to a surface directly from the container by:
  (A) pouring;
  (B) siphoning;
  (C) brushing;
  (D) rolling;
  (E) padding;
  (F) ragging; or
  (G) other means;
shall be closed when not in use.
(2) Containers of any VOC-containing materials used for thinning and cleanup shall be closed when not in use.

(f) No person who applies or solicits the application of any AIM coating shall apply a coating that is thinned to exceed the applicable VOC limit specified in subsection (b).

(g) No person shall apply or solicit the application of any rust preventative coating for industrial use, unless the rust preventative coating complies with the industrial maintenance coating VOC content limit specified in subsection (b).

(h) If a coating does not meet any of the definitions for the specialty coatings categories listed in subsection (b), the VOC content limit shall be determined by classifying the coating as a flat coating, nonflat coating, or nonflat-high-gloss coating as defined in section 2 of this rule. The corresponding flat or nonflat coating VOC content limit shall apply.

(Air Pollution Control Board; 326 IAC 8-14-3; filed Nov 1, 2010, 11:58 a.m.: 20101201-IR-326060604FRA)

326 IAC 8-14-4 Container labeling

Authority: IC 13-14-8; IC 13-17-3-4
Affected: IC 13-12

Sec. 4. On and after October 1, 2011, each manufacturer of any AIM coating subject to this rule shall prominently display the following information on the coating container or label in which the coating is sold or distributed:
(1) A date code, as follows:
  (A) The date the coating was manufactured, or a date code representing the date, shall be indicated on the label, lid, or bottom of the container.
  (B) If the manufacturer uses a date code for any coating, the manufacturer shall file an explanation of each code with the department.
(2) Thinning recommendations, as follows:
  (A) A statement of the manufacturer's recommendation regarding thinning of the coating shall be indicated on the label or lid of the container.
  (B) This requirement does not apply to the thinning of architectural coatings with water.
  (C) If thinning of a coating prior to use is not necessary, the recommendation must specify that the coating is to be applied without thinning.
(3) VOC content, as follows:
  (A) Each container of any coating subject to this rule shall display either the maximum or the actual VOC content of the coating, as supplied, including the maximum thinning recommended by the manufacturer.
  (B) VOC content shall be displayed in grams of VOC per liter of coating.
  (C) VOC content displayed shall be:
    (i) calculated using product formulation data; or
    (ii) determined using the test methods in section 6(b) of this rule.
  The equations in section 6(a) of this rule shall be used to calculate VOC content.
(4) The label or the lid of the container in which an industrial maintenance coating is sold or

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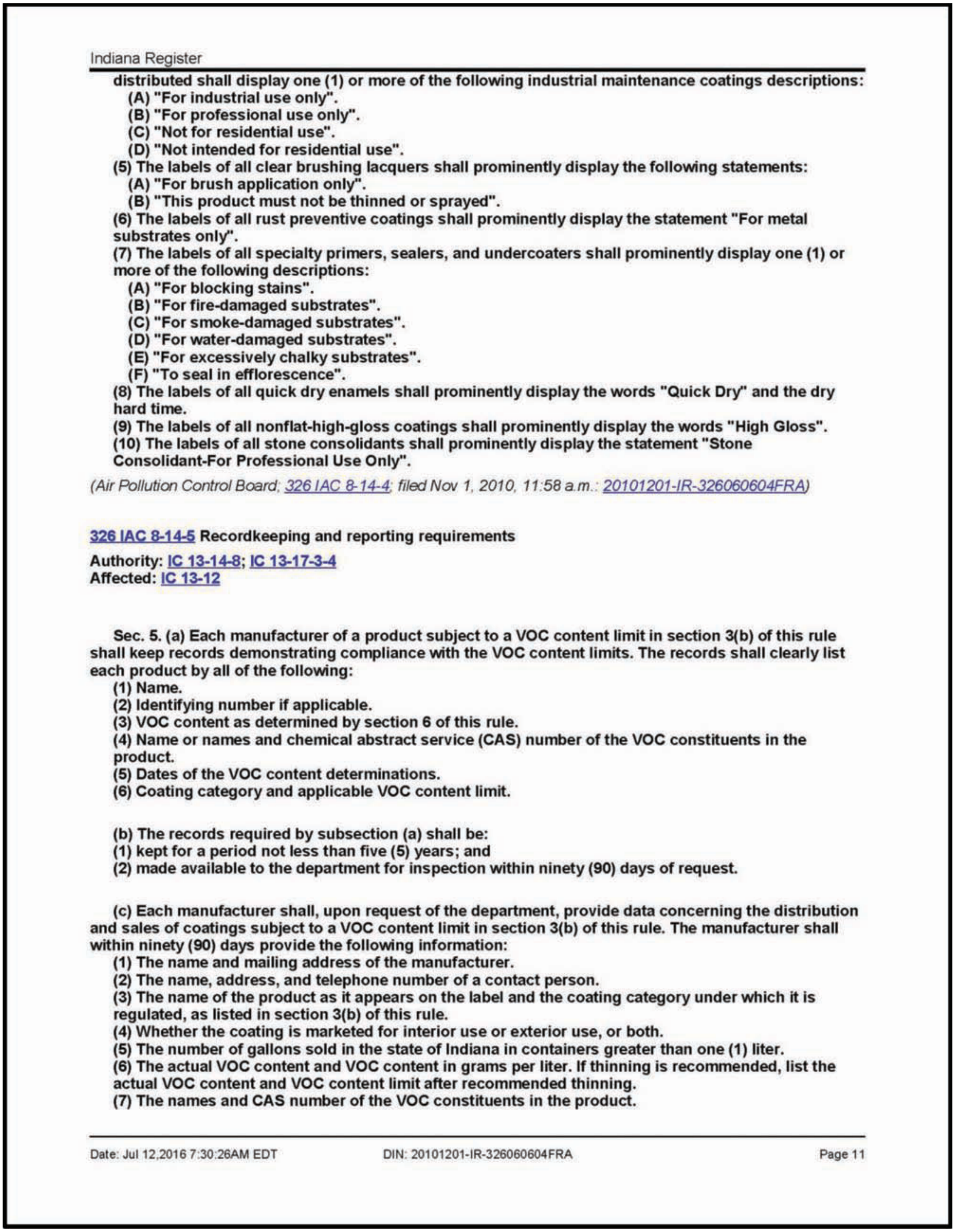
Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



distributed shall display one (1) or more of the following industrial maintenance coatings descriptions:
  (A) "For industrial use only".
  (B) "For professional use only".
  (C) "Not for residential use".
  (D) "Not intended for residential use".
(5) The labels of all clear brushing lacquers shall prominently display the following statements:
  (A) "For brush application only".
  (B) "This product must not be thinned or sprayed".
(6) The labels of all rust preventive coatings shall prominently display the statement "For metal substrates only".
(7) The labels of all specialty primers, sealers, and undercoaters shall prominently display one (1) or more of the following descriptions:
  (A) "For blocking stains".
  (B) "For fire-damaged substrates".
  (C) "For smoke-damaged substrates".
  (D) "For water-damaged substrates".
  (E) "For excessively chalky substrates".
  (F) "To seal in efflorescence".
(8) The labels of all quick dry enamels shall prominently display the words "Quick Dry" and the dry hard time.
(9) The labels of all nonflat-high-gloss coatings shall prominently display the words "High Gloss".
(10) The labels of all stone consolidants shall prominently display the statement "Stone Consolidant-For Professional Use Only".

(Air Pollution Control Board; 326 IAC 8-14-4; filed Nov 1, 2010, 11:58 a.m.: 20101201-IR-326060604FRA)

326 IAC 8-14-5 Recordkeeping and reporting requirements

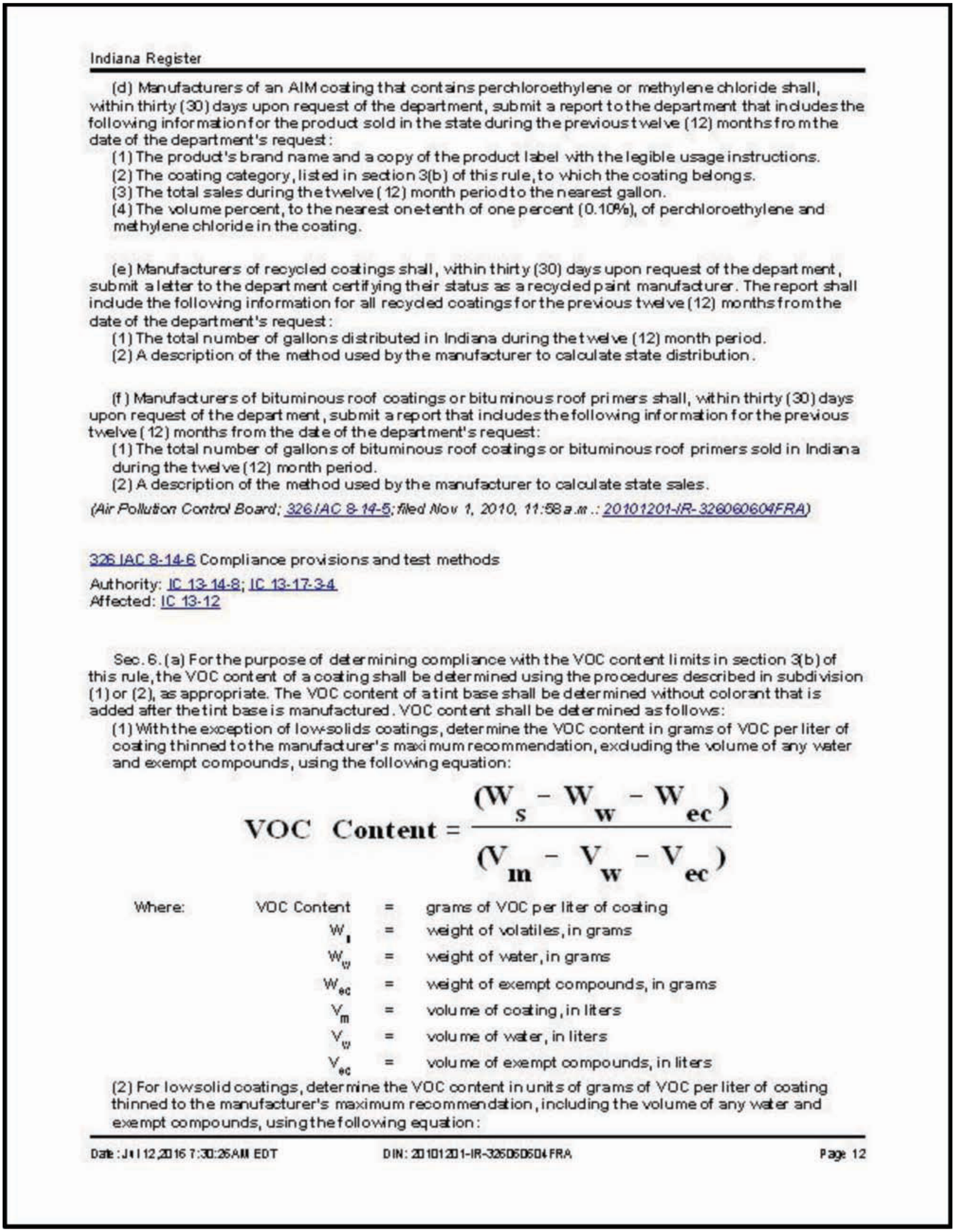
Authority: IC 13-14-8; IC 13-17-3-4
Affected: IC 13-12

Sec. 5. (a) Each manufacturer of a product subject to a VOC content limit in section 3(b) of this rule shall keep records demonstrating compliance with the VOC content limits. The records shall clearly list each product by all of the following:
(1) Name.
(2) Identifying number if applicable.
(3) VOC content as determined by section 6 of this rule.
(4) Name or names and chemical abstract service (CAS) number of the VOC constituents in the product.
(5) Dates of the VOC content determinations.
(6) Coating category and applicable VOC content limit.

(b) The records required by subsection (a) shall be:
(1) kept for a period not less than five (5) years; and
(2) made available to the department for inspection within ninety (90) days of request.

(c) Each manufacturer shall, upon request of the department, provide data concerning the distribution and sales of coatings subject to a VOC content limit in section 3(b) of this rule. The manufacturer shall within ninety (90) days provide the following information:
(1) The name and mailing address of the manufacturer.
(2) The name, address, and telephone number of a contact person.
(3) The name of the product as it appears on the label and the coating category under which it is regulated, as listed in section 3(b) of this rule.
(4) Whether the coating is marketed for interior use or exterior use, or both.
(5) The number of gallons sold in the state of Indiana in containers greater than one (1) liter.
(6) The actual VOC content and VOC content in grams per liter. If thinning is recommended, list the actual VOC content and VOC content limit after recommended thinning.
(7) The names and CAS number of the VOC constituents in the product.

Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



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(d) Manufacturers of an AIM coating that contains perchloroethylene or methylene chloride shall, within thirty (30) days upon request of the department, submit a report to the department that includes the following information for the product sold in the state during the previous twelve (12) months from the date of the department's request:

(1) The product's brand name and a copy of the product label with the legible usage instructions.
(2) The coating category, listed in section 3(b) of this rule, to which the coating belongs.
(3) The total sales during the twelve (12) month period to the nearest gallon.
(4) The volume percent, to the nearest one-tenth of one percent (0.10%), of perchloroethylene and methylene chloride in the coating.

(e) Manufacturers of recycled coatings shall, within thirty (30) days upon request of the department, submit a letter to the department certifying their status as a recycled paint manufacturer. The report shall include the following information for all recycled coatings for the previous twelve (12) months from the date of the department's request:

(1) The total number of gallons distributed in Indiana during the twelve (12) month period.
(2) A description of the method used by the manufacturer to calculate state distribution.

(f) Manufacturers of bituminous roof coatings or bituminous roof primers shall, within thirty (30) days upon request of the department, submit a report that includes the following information for the previous twelve (12) months from the date of the department's request:

(1) The total number of gallons of bituminous roof coatings or bituminous roof primers sold in Indiana during the twelve (12) month period.
(2) A description of the method used by the manufacturer to calculate state sales.

(Air Pollution Control Board; 326 IAC 8-14-5; filed Nov 1, 2010, 11:58 a.m.: 20101201-IR-326060604FRA)

326 IAC 8-14-6 Compliance provisions and test methods

Authority: IC 13-14-8; IC 13-17-3-4
Affected: IC 13-12

Sec. 6. (a) For the purpose of determining compliance with the VOC content limits in section 3(b) of this rule, the VOC content of a coating shall be determined using the procedures described in subdivision (1) or (2), as appropriate. The VOC content of a tint base shall be determined without colorant that is added after the tint base is manufactured. VOC content shall be determined as follows:

(1) With the exception of low-solids coatings, determine the VOC content in grams of VOC per liter of coating thinned to the manufacturer's maximum recommendation, excluding the volume of any water and exempt compounds, using the following equation:

$$\text{VOC Content} = \frac{(W_s - W_w - W_{ec})}{(V_m - V_w - V_{ec})}$$

Where: VOC Content = grams of VOC per liter of coating
W_s = weight of volatiles, in grams
W_w = weight of water, in grams
W_{ec} = weight of exempt compounds, in grams
V_m = volume of coating, in liters
V_w = volume of water, in liters
V_{ec} = volume of exempt compounds, in liters

(2) For low-solid coatings, determine the VOC content in units of grams of VOC per liter of coating thinned to the manufacturer's maximum recommendation, including the volume of any water and exempt compounds, using the following equation:

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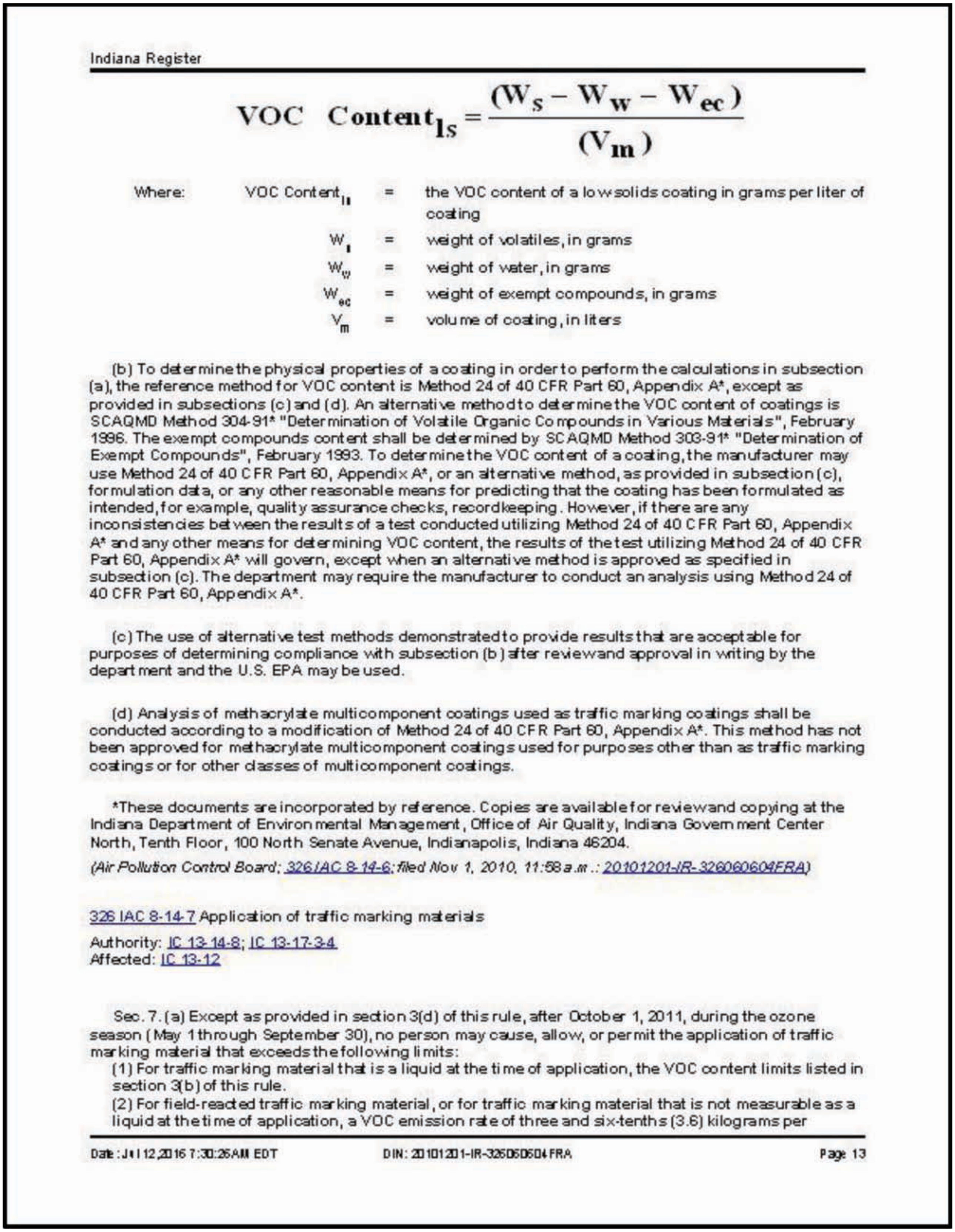
Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



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$$\text{VOC Content}_{ls} = \frac{(W_s - W_w - W_{ec})}{(V_m)}$$

Where: VOC Content_{ls} = the VOC content of a low solids coating in grams per liter of coating

W_s = weight of volatiles, in grams

W_w = weight of water, in grams

W_{ec} = weight of exempt compounds, in grams

V_m = volume of coating, in liters

(b) To determine the physical properties of a coating in order to perform the calculations in subsection (a), the reference method for VOC content is Method 24 of 40 CFR Part 60, Appendix A*, except as provided in subsections (c) and (d). An alternative method to determine the VOC content of coatings is SCAQMD Method 304-91* "Determination of Volatile Organic Compounds in Various Materials", February 1996. The exempt compounds content shall be determined by SCAQMD Method 303-91* "Determination of Exempt Compounds", February 1993. To determine the VOC content of a coating, the manufacturer may use Method 24 of 40 CFR Part 60, Appendix A*, or an alternative method, as provided in subsection (c), formulation data, or any other reasonable means for predicting that the coating has been formulated as intended, for example, quality assurance checks, recordkeeping. However, if there are any inconsistencies between the results of a test conducted utilizing Method 24 of 40 CFR Part 60, Appendix A* and any other means for determining VOC content, the results of the test utilizing Method 24 of 40 CFR Part 60, Appendix A* will govern, except when an alternative method is approved as specified in subsection (c). The department may require the manufacturer to conduct an analysis using Method 24 of 40 CFR Part 60, Appendix A*.

(c) The use of alternative test methods demonstrated to provide results that are acceptable for purposes of determining compliance with subsection (b) after review and approval in writing by the department and the U.S. EPA may be used.

(d) Analysis of methacrylate multicomponent coatings used as traffic marking coatings shall be conducted according to a modification of Method 24 of 40 CFR Part 60, Appendix A*. This method has not been approved for methacrylate multicomponent coatings used for purposes other than as traffic marking coatings or for other classes of multicomponent coatings.

*These documents are incorporated by reference. Copies are available for review and copying at the Indiana Department of Environmental Management, Office of Air Quality, Indiana Government Center North, Tenth Floor, 100 North Senate Avenue, Indianapolis, Indiana 46204.

(Air Pollution Control Board; 326 IAC 8-14-6; filed Nov 1, 2010, 11:58 a.m.: 20101201-IR-326060604FRA)

326 IAC 8-14-7 Application of traffic marking materials

Authority: IC 13-14-8; IC 13-17-3-4
Affected: IC 13-12

Sec. 7. (a) Except as provided in section 3(d) of this rule, after October 1, 2011, during the ozone season (May 1 through September 30), no person may cause, allow, or permit the application of traffic marking material that exceeds the following limits:

(1) For traffic marking material that is a liquid at the time of application, the VOC content limits listed in section 3(b) of this rule.

(2) For field-reacted traffic marking material, or for traffic marking material that is not measurable as a liquid at the time of application, a VOC emission rate of three and six-tenths (3.6) kilograms per

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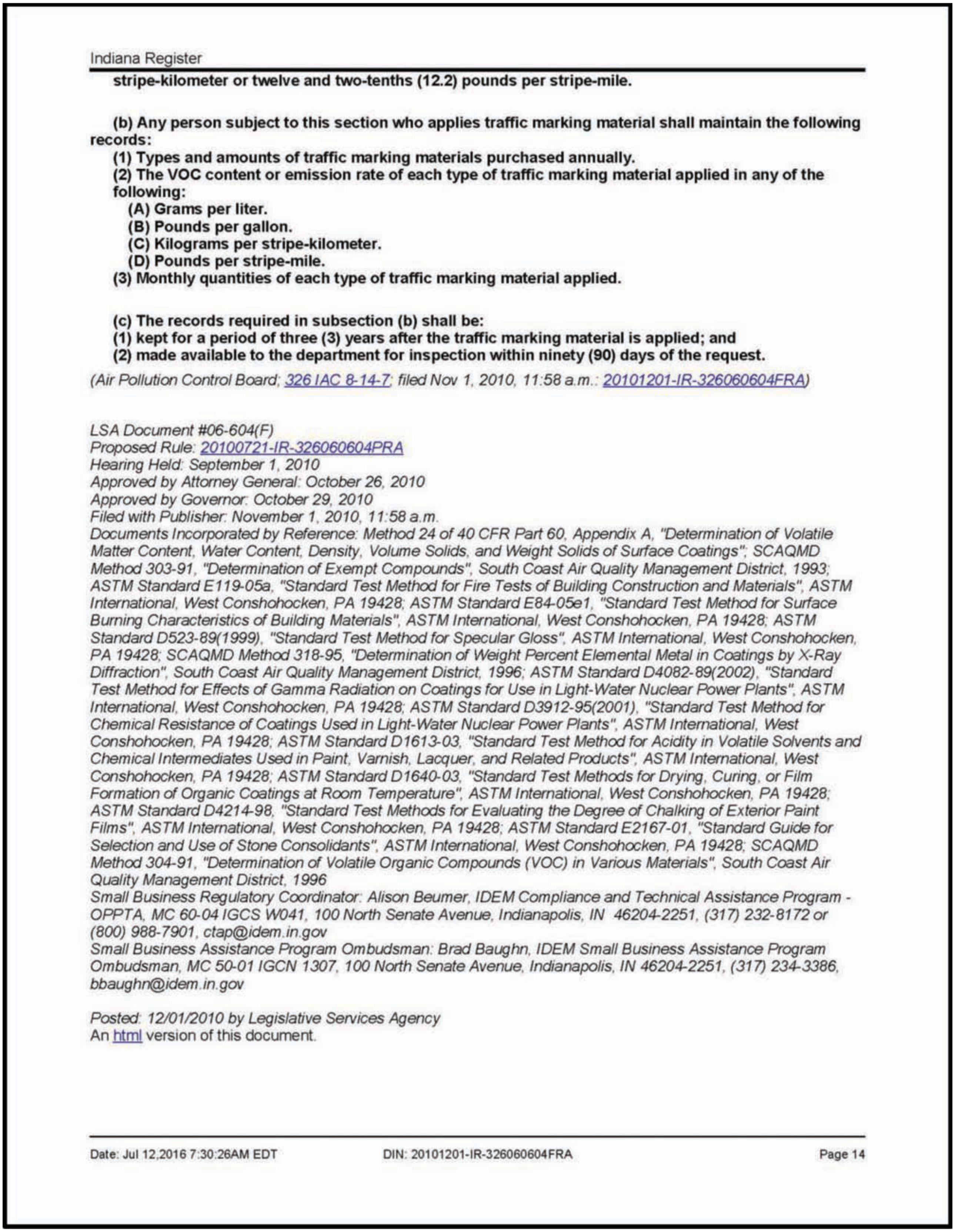
Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.



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stripe-kilometer or twelve and two-tenths (12.2) pounds per stripe-mile.

(b) Any person subject to this section who applies traffic marking material shall maintain the following records:
(1) Types and amounts of traffic marking materials purchased annually.
(2) The VOC content or emission rate of each type of traffic marking material applied in any of the following:
  (A) Grams per liter.
  (B) Pounds per gallon.
  (C) Kilograms per stripe-kilometer.
  (D) Pounds per stripe-mile.
(3) Monthly quantities of each type of traffic marking material applied.

(c) The records required in subsection (b) shall be:
(1) kept for a period of three (3) years after the traffic marking material is applied; and
(2) made available to the department for inspection within ninety (90) days of the request.

(Air Pollution Control Board; 326 IAC 8-14-7; filed Nov 1, 2010, 11:58 a.m.: 20101201-IR-326060604FRA)

LSA Document #06-604(F)
Proposed Rule: 20100721-IR-326060604PRA
Hearing Held: September 1, 2010
Approved by Attorney General: October 26, 2010
Approved by Governor: October 29, 2010
Filed with Publisher: November 1, 2010, 11:58 a.m.
Documents Incorporated by Reference: Method 24 of 40 CFR Part 60, Appendix A, "Determination of Volatile Matter Content, Water Content, Density, Volume Solids, and Weight Solids of Surface Coatings"; SCAQMD Method 303-91, "Determination of Exempt Compounds", South Coast Air Quality Management District, 1993; ASTM Standard E119-05a, "Standard Test Method for Fire Tests of Building Construction and Materials", ASTM International, West Conshohocken, PA 19428; ASTM Standard E84-05e1, "Standard Test Method for Surface Burning Characteristics of Building Materials", ASTM International, West Conshohocken, PA 19428; ASTM Standard D523-89(1999), "Standard Test Method for Specular Gloss", ASTM International, West Conshohocken, PA 19428; SCAQMD Method 318-95, "Determination of Weight Percent Elemental Metal in Coatings by X-Ray Diffraction", South Coast Air Quality Management District, 1996; ASTM Standard D4082-89(2002), "Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light-Water Nuclear Power Plants", ASTM International, West Conshohocken, PA 19428; ASTM Standard D3912-95(2001), "Standard Test Method for Chemical Resistance of Coatings Used in Light-Water Nuclear Power Plants", ASTM International, West Conshohocken, PA 19428; ASTM Standard D1613-03, "Standard Test Method for Acidity in Volatile Solvents and Chemical Intermediates Used in Paint, Varnish, Lacquer, and Related Products", ASTM International, West Conshohocken, PA 19428; ASTM Standard D1640-03, "Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings at Room Temperature", ASTM International, West Conshohocken, PA 19428; ASTM Standard D4214-98, "Standard Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films", ASTM International, West Conshohocken, PA 19428; ASTM Standard E2167-01, "Standard Guide for Selection and Use of Stone Consolidants", ASTM International, West Conshohocken, PA 19428; SCAQMD Method 304-91, "Determination of Volatile Organic Compounds (VOC) in Various Materials", South Coast Air Quality Management District, 1996
Small Business Regulatory Coordinator: Alison Beumer, IDEM Compliance and Technical Assistance Program - OPPTA, MC 60-04 IGCS W041, 100 North Senate Avenue, Indianapolis, IN 46204-2251, (317) 232-8172 or (800) 988-7901, ctap@idem.in.gov
Small Business Assistance Program Ombudsman: Brad Baughn, IDEM Small Business Assistance Program Ombudsman, MC 50-01 IGCN 1307, 100 North Senate Avenue, Indianapolis, IN 46204-2251, (317) 234-3386, bbaughn@idem.in.gov

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Figure A.1 (cont.) Final rule for volatile organic compound (VOC) limit.

APPENDIX B. SPECIMEN CRACK LOCATIONS

The locations of the cracks were recorded for the cracked specimens to later facilitate the condition assessment of the bars at recorded crack locations. Distances were measured on the top face of the specimen from the front face of the concrete (resistor side) to the locations where the cracks intersected with the top left and top right longitudinal bars. The typical specimen had three cracks located at the transverse bars; however, some specimens displayed a fourth crack located approximately halfway between cracks at transverse bars. Figure B.1 illustrates the crack location measurements recorded for Specimen No. 50 from Group 10. The crack locations for each cracked specimen in Groups 1 to 19 are shown in Table B.1. Each measurement is designated by the crack number and the bar at which it is measured. For example, the intersection of the first crack with the top left longitudinal bar is identified as "CR1-TL."

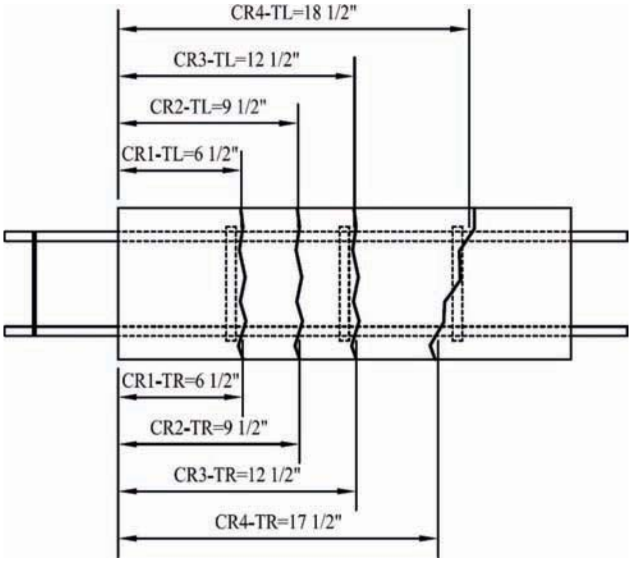


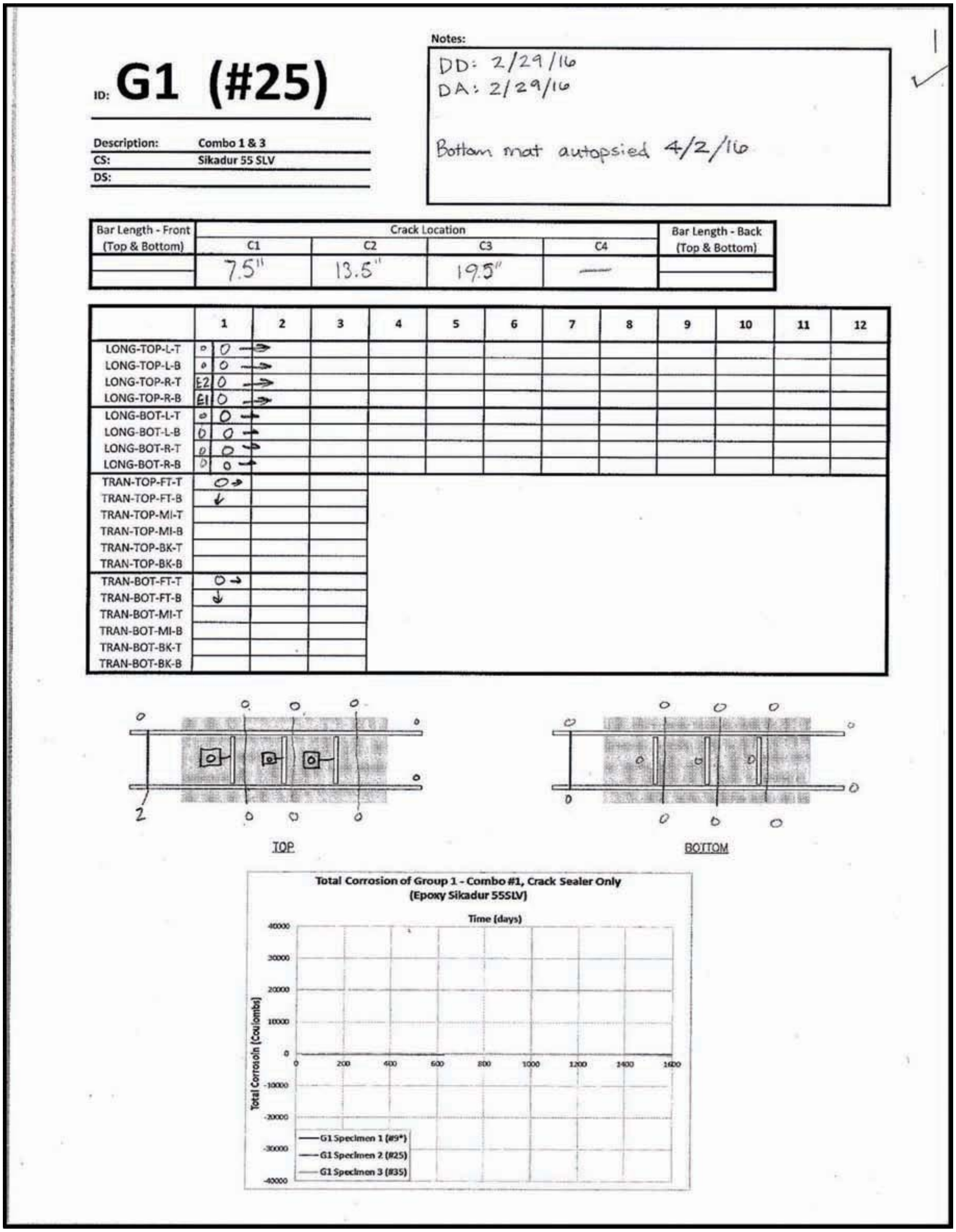
Figure B.1 Crack distance measurements for Specimen No. 50.

Group No.	Specimen No.	No. of Cracks	Distance to 1st Crack, CR1 (in.)		Distance to 2nd Crack, CR2 (in.)		Distance to 3rd Crack, CR3 (in.)		Distance to 4th Crack, CR4 (in.)	
			CR1-TL	CR1-TR	CR2-TL	CR2-TR	CR3-TL	CR3-TR	CR4-TL	CR4-TR
1	25	3	7-1/2		13-1/2		19-1/2			
	35	3	6-1/2		13	14	18	19		
2	3	4	4-1/2	3-1/2	7-1/2		12-1/2		18-1/2	
	23	3	6	5-1/2	11		18	18-1/2		
3	11	3	5-1/2	6-1/2	12-1/2		18-1/2			
	15	4	5-1/2		11	10	12	12-1/2	18-1/2	18
4	13	3	6-1/2	5-1/2	13-1/2	13	18-1/2			
	18	4	3		7-1/2		12		18	
5	12	3	5-1/2		13	12	18-1/2			
	42	4	5-1/2		12		15		18	
6	16	3	5-1/2		12-1/2		16			
	49	4	7	6	12-1/2		14-1/2		18-1/2	
7	46	3	6-1/2		12		18-1/2			
	47	3	6		12		18-1/2	19		
8	24	3	6-1/2	6	12	12-1/2	18-1/2			
	52	3	6-1/2	5-1/2	11		18-1/2			
9	5	4	5-1/2		8		12-1/2		18-1/2	
	40	3	5-1/2		12		18			
10	27	4	6-1/2		12		14-1/2		20	
	50	4	6-1/2		9-1/2		12-1/2		18-1/2	17
11	22	3	6		12		18			
	48	3	5-1/2		11	13	18			
12	1	3	8		12		16-1/2			
	26	4	5-1/2		12		16		19	18
13	21	3	7	6	13-1/2		18-1/2			
	43	4	7	5-1/2	8	8-1/2	13	12	19	18
14	37	4	6		10		13		19	
	45	3	6		12	13	18	18-1/2		
15	17	3	6		12		17			
	41	3	5-1/2	6	12		18	18-1/2		
16	29	3	7	6	13-1/2	12	18-1/2	18		
	33	3	5-1/2		12		18-1/2	18		
17	31	3	6-1/2	7	12		18-1/2	19		
	32	3	6		12-1/2		18			
18	54	3	6-1/2	7	12-1/2		18-1/2			
	55	3	6	5-1/2	12		17-1/2	18		
19	56	3	6		12		19			
	58	3	6-1/2	5-1/2	12		17-1/2	18		

Figure B.2 Specimen crack locations.

APPENDIX C. AUTOPSY NOTES

The autopsy notes for the 60 specimens autopsied in 2016 are presented in Figures C.1 to C.60. Each page includes a description of the test variables, the date the specimen was disconnected from the datalogger ("DD"), the date the specimen was autopsied ("DA"), the measured crack locations, observations from the autopsy, and the visual ratings assigned for both autopsy rating methods.



ID: G1 (#25)

Description: Combo 1 & 3
CS: Sikadur 55 SLV
DS:

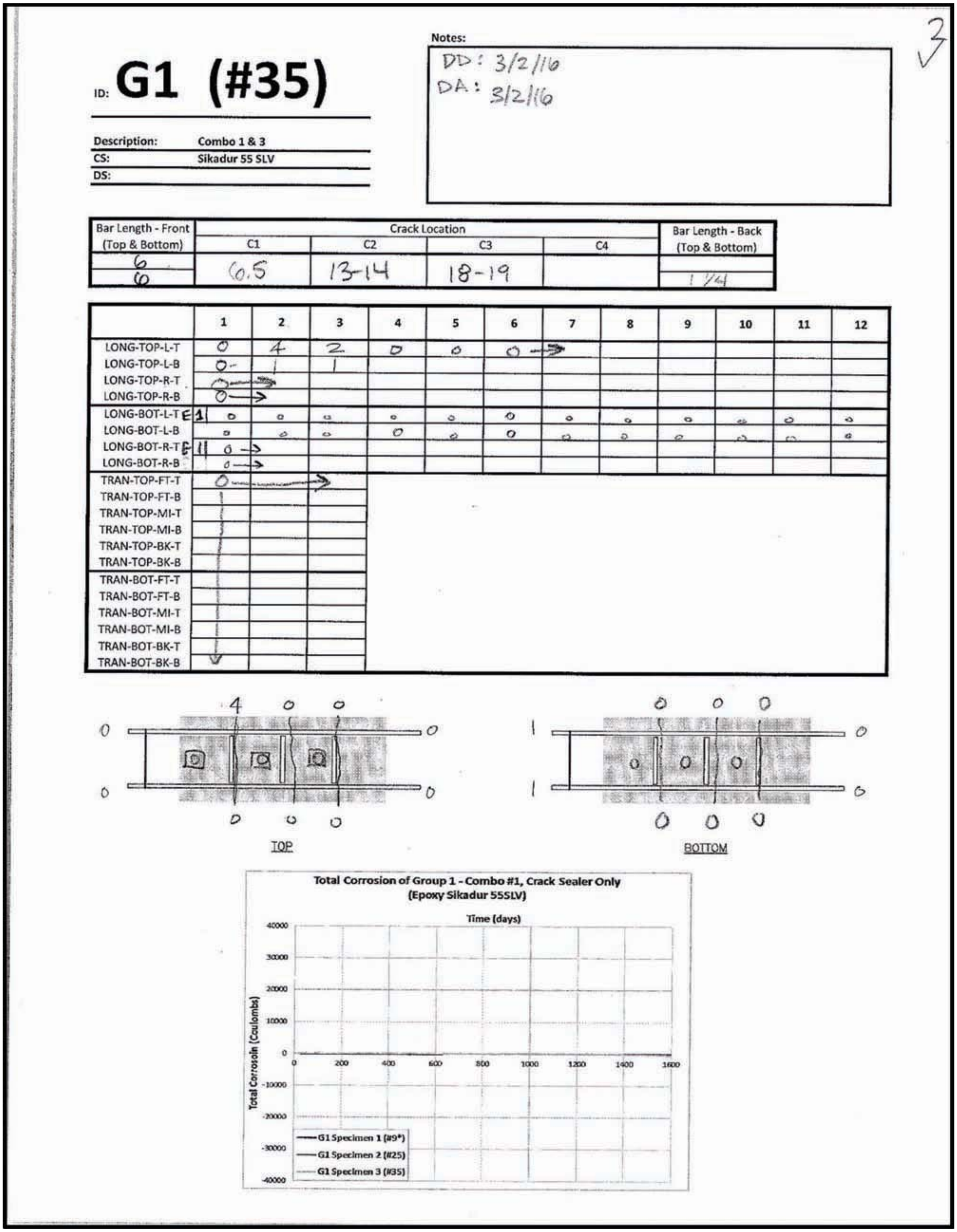
Notes:
DD: 2/29/16
DA: 2/29/16

Bottom mat autopsied 4/2/16

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	7.5"	13.5"	19.5"	—	

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0 →											
LONG-TOP-L-B	0 0 →											
LONG-TOP-R-T	E2 0 →											
LONG-TOP-R-B	E1 0 →											
LONG-BOT-L-T	0 0 →											
LONG-BOT-L-B	0 0 →											
LONG-BOT-R-T	0 0 →											
LONG-BOT-R-B	0 0 →											
TRAN-TOP-FT-T	0 →											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.1 Autopsy notes for Specimen No. 25.



3

ID: **G1 (#35)**

Notes:
DD: 3/2/16
DA: 3/2/16

Description:	Combo 1 & 3
CS:	Sikadur 55 SLV
DS:	

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
6	6.5	13-14	18-19		
6					1 1/4

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0	4	2	0	0	0 →						
LONG-TOP-L-B	0 -	1	1									
LONG-TOP-R-T	0 →											
LONG-TOP-R-B	0 →											
LONG-BOT-L-T E1	0	0	0	0	0	0	0	0	0	0	0	0
LONG-BOT-L-B	0	0	0	0	0	0	0	0	0	0	0	0
LONG-BOT-R-T E11	0 →											
LONG-BOT-R-B	0 →											
TRAN-TOP-FT-T	0 →											
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.2 Autopsy notes for Specimen No. 35.

3 ✓

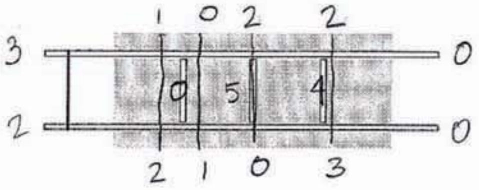
ID: **G2 (#3)**

Description: Combo 1
CS:
DS: MasterProtect H 440 HZ

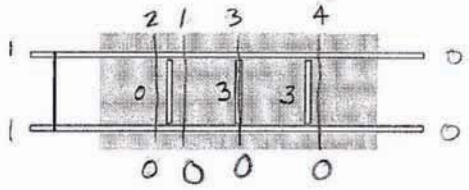
Notes:
DD 3/3/16
DA 3/5/16

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
6 6	4.5-3.5	7.5	12.5	18.5	3 1/4 1 1/4

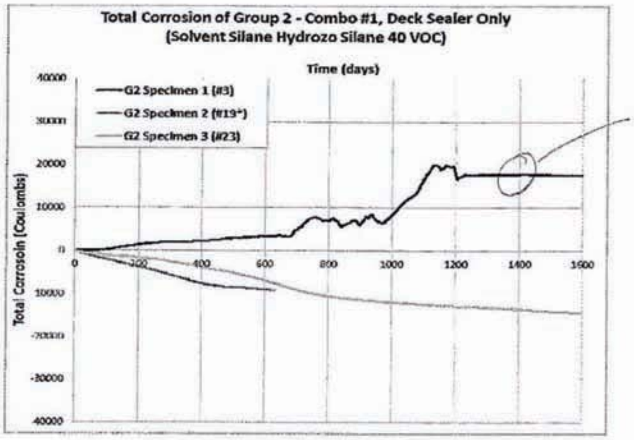
	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	2 0	1	0	0	0	1	2	0	1	2	0	0
LONG-TOP-L-B	1 0	0	0	0	1	2	1	0	0	0	0	0
LONG-TOP-R-T	2 0	2	1	1	0	0	0	0	0	1	0	0
LONG-TOP-R-B	2 0	1	1	0	0	0	0	0	0	2	0	0
LONG-BOT-L-T	1 0	1	1	0	0	1	2	0	2	4	0	0
LONG-BOT-L-B	1 0	1	1	0	0	2	0	0	2	2	0	0
LONG-BOT-R-T	1 0	0 →										
LONG-BOT-R-B	1 0	0 →										
TRAN-TOP-FT-T	0	0	0									
TRAN-TOP-FT-B	0	0	0									
TRAN-TOP-MI-T	2	8	8									
TRAN-TOP-MI-B	0	1	0									
TRAN-TOP-BK-T	1	2	8									
TRAN-TOP-BK-B	0	0	1									
TRAN-BOT-FT-T	0	0	0									
TRAN-BOT-FT-B	0	0	0									
TRAN-BOT-MI-T	2	1	4									
TRAN-BOT-MI-B	1	1	4									
TRAN-BOT-BK-T	0	0	0									
TRAN-BOT-BK-B	0	1	2									



TOP

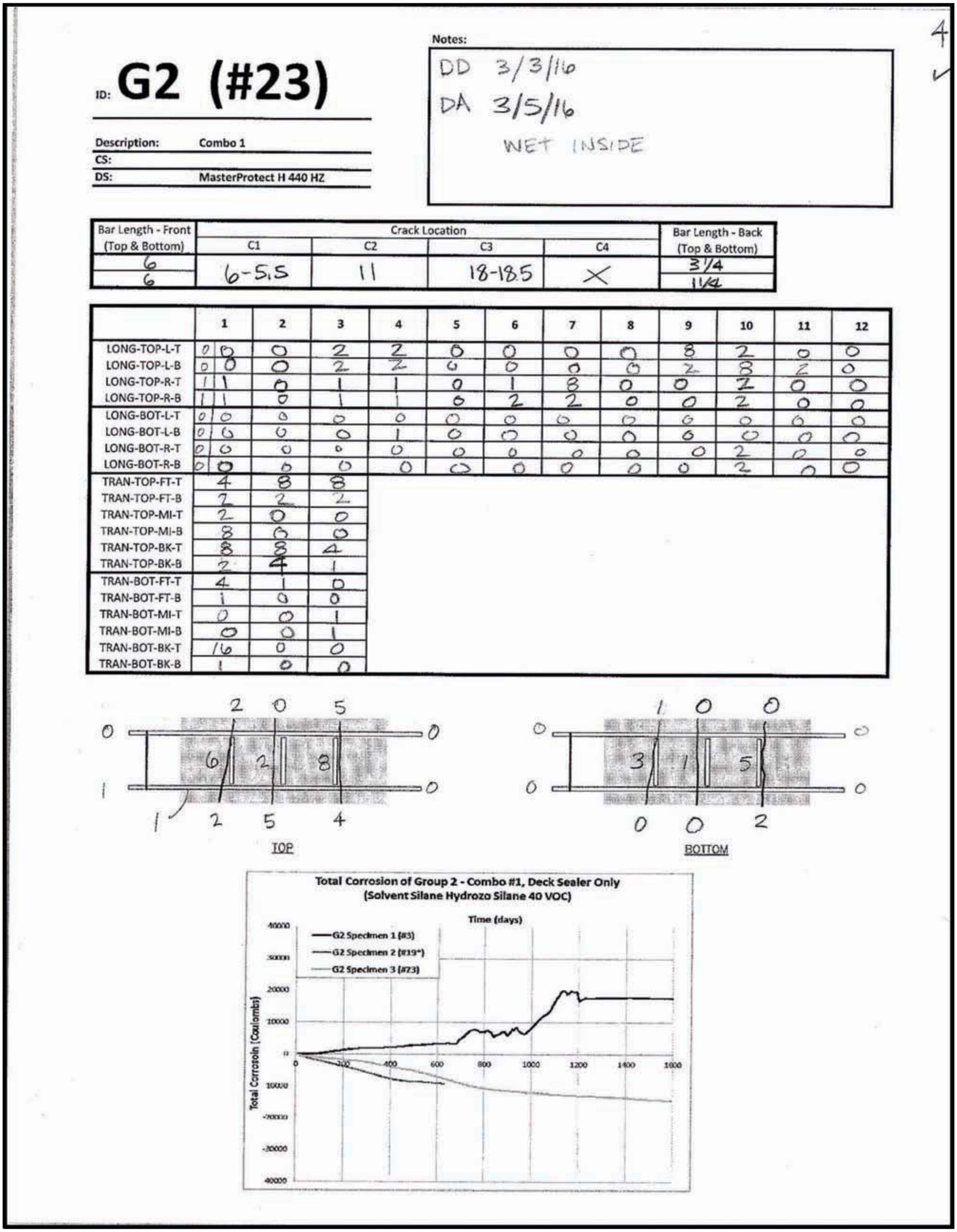


BOTTOM



Check Bottom Bars

Figure C.3 Autopsy notes for Specimen No. 3.



4

ID: **G2 (#23)**

Description:	Combo 1
CS:	
DS:	MasterProtect H 440 HZ

Notes:

DD 3/3/16

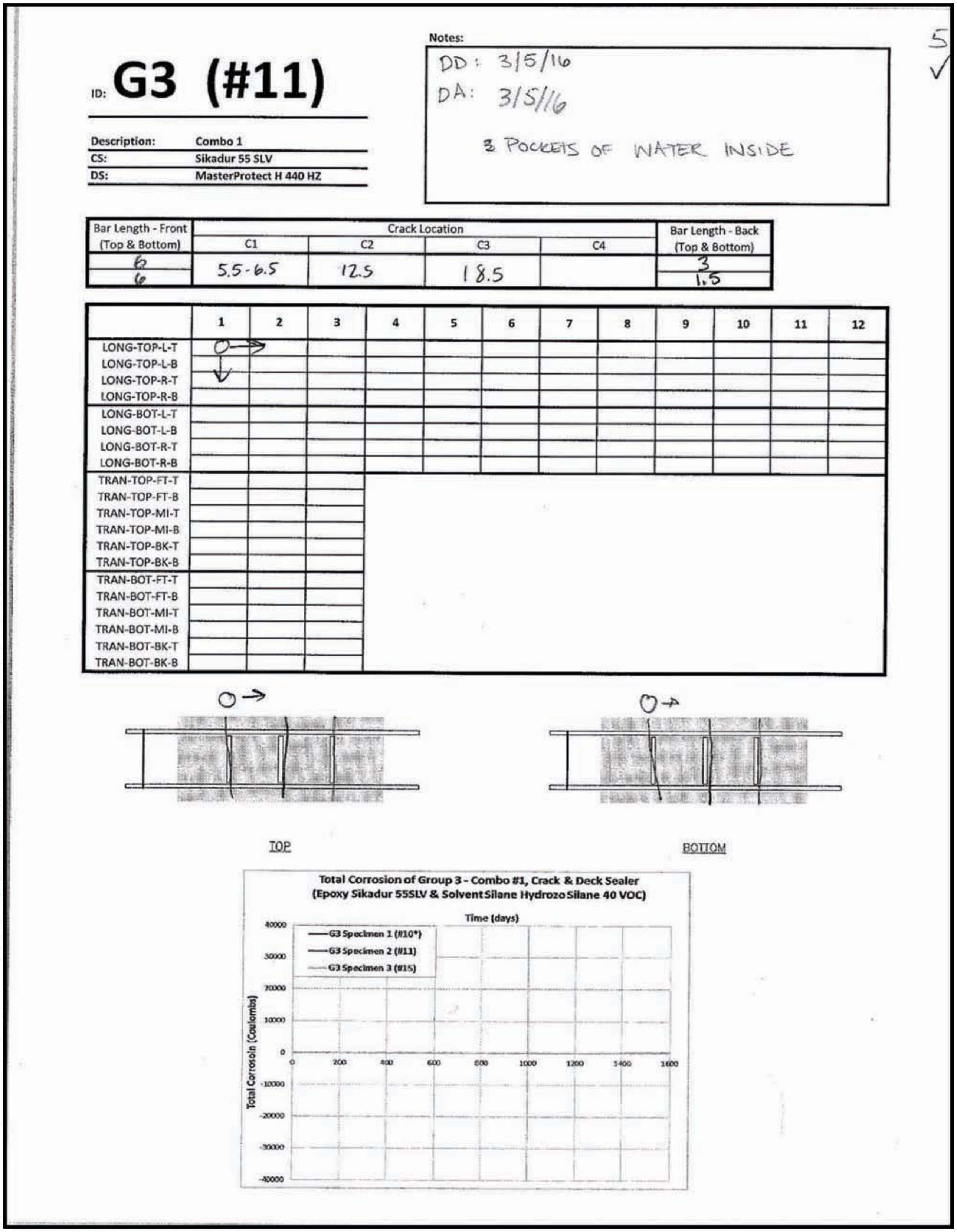
DA 3/5/16

WET INSIDE

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
6	6-5.5	11	18-18.5	X	3 1/4
6					1 1/4

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0	0	2	2	0	0	0	0	8	2	0	0
LONG-TOP-L-B	0 0	0	2	2	0	0	0	0	2	8	2	0
LONG-TOP-R-T	1 1	0	1	1	0	1	8	0	0	2	0	0
LONG-TOP-R-B	1 1	0	1	1	0	2	2	0	0	2	0	0
LONG-BOT-L-T	0 0	0	0	0	0	0	0	0	0	0	0	0
LONG-BOT-L-B	0 0	0	0	1	0	0	0	0	0	0	0	0
LONG-BOT-R-T	0 0	0	0	0	0	0	0	0	0	2	0	0
LONG-BOT-R-B	0 0	0	0	0	0	0	0	0	0	2	0	0
TRAN-TOP-FT-T	4	8	8									
TRAN-TOP-FT-B	2	2	2									
TRAN-TOP-MI-T	2	0	0									
TRAN-TOP-MI-B	8	0	0									
TRAN-TOP-BK-T	8	8	4									
TRAN-TOP-BK-B	2	4	1									
TRAN-BOT-FT-T	4	1	0									
TRAN-BOT-FT-B	1	0	0									
TRAN-BOT-MI-T	0	0	1									
TRAN-BOT-MI-B	0	0	1									
TRAN-BOT-BK-T	16	0	0									
TRAN-BOT-BK-B	1	0	0									

Figure C.4 Autopsy notes for Specimen No. 23.



5
✓

ID: **G3 (#11)**

Description: Combo 1
CS: Sikadur 55 SLV
DS: MasterProtect H 440 HZ

Notes:
DD: 3/5/16
DA: 3/5/16

3 POCKETS OF WATER INSIDE

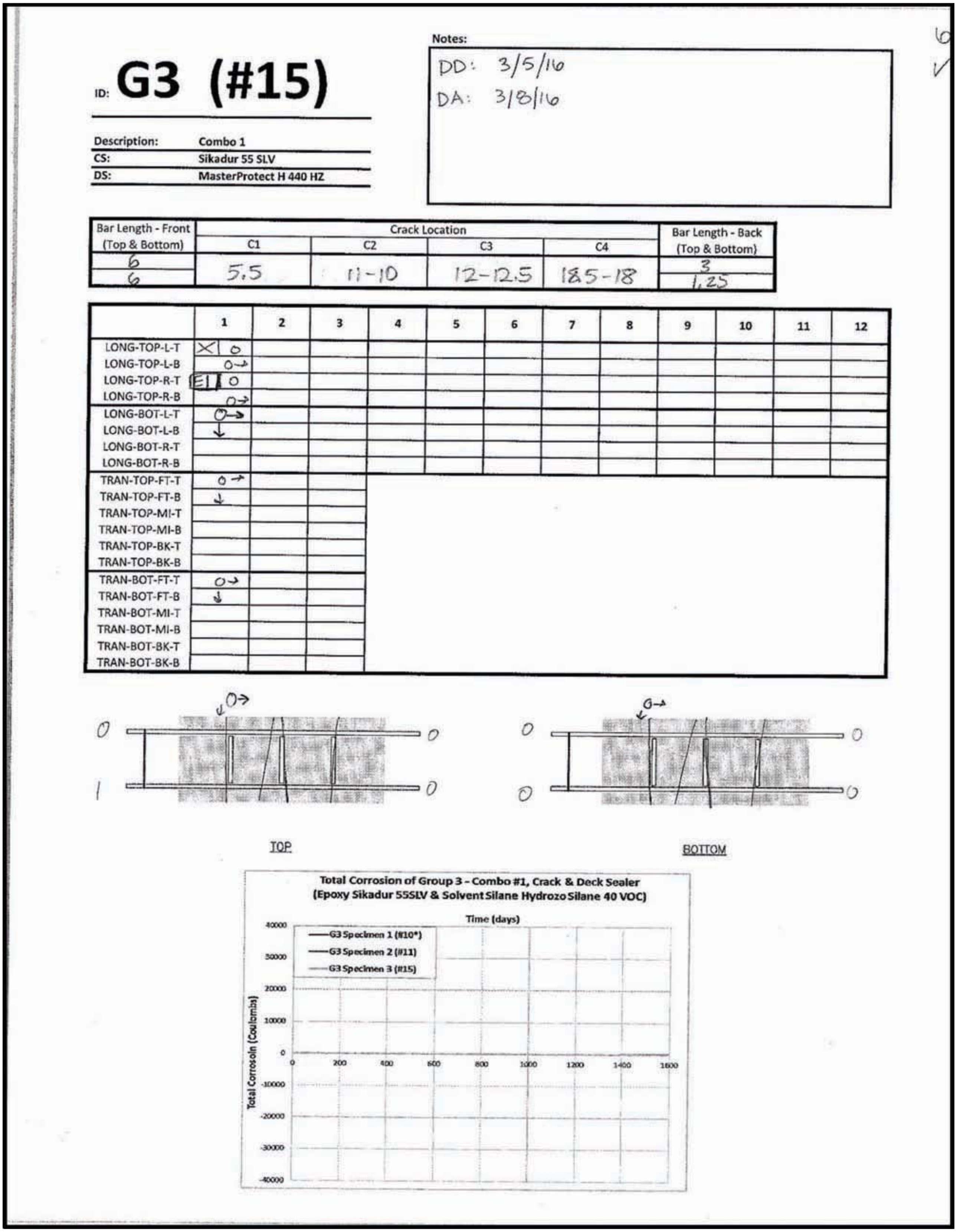
Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
6	5.5-6.5	12.5	18.5		3
6					1.5

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	○→											
LONG-TOP-L-B	↓											
LONG-TOP-R-T												
LONG-TOP-R-B												
LONG-BOT-L-T												
LONG-BOT-L-B												
LONG-BOT-R-T												
LONG-BOT-R-B												
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

○→
TOP

○→
BOTTOM

Figure C.5 Autopsy notes for Specimen No. 11.



6
✓

ID: **G3 (#15)**

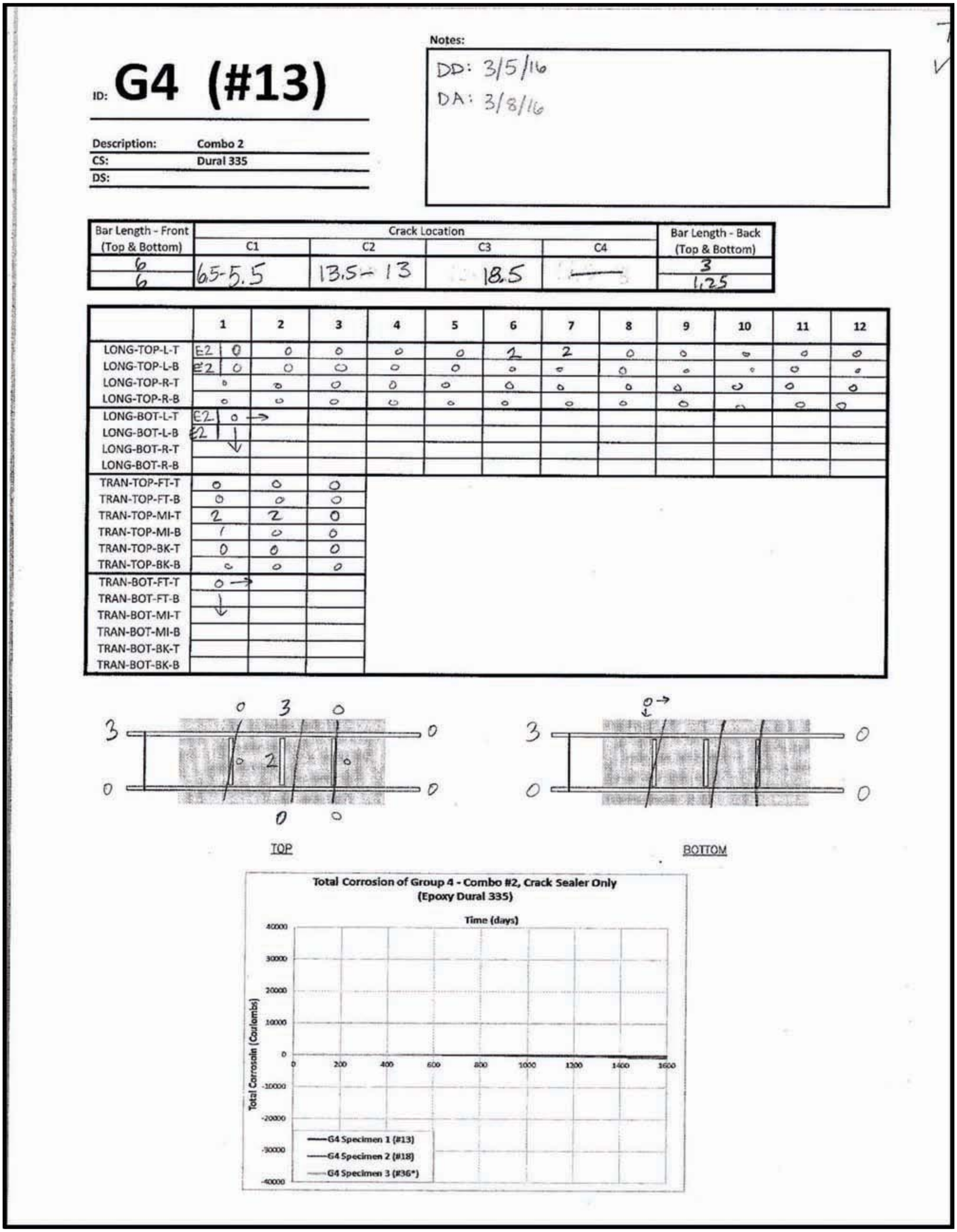
Notes:
DD: 3/5/16
DA: 3/8/16

Description:	Combo 1
CS:	Sikadur 55 SLV
DS:	MasterProtect H 440 HZ

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
6 6	5.5	11-10	12-12.5	18.5-18	3 1.25

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	☒ 0											
LONG-TOP-L-B	0→											
LONG-TOP-R-T	E 0											
LONG-TOP-R-B	0→											
LONG-BOT-L-T	0→											
LONG-BOT-L-B	↓											
LONG-BOT-R-T												
LONG-BOT-R-B												
TRAN-TOP-FT-T	0→											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0→											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.6 Autopsy notes for Specimen No. 15.



ID: **G4 (#13)**

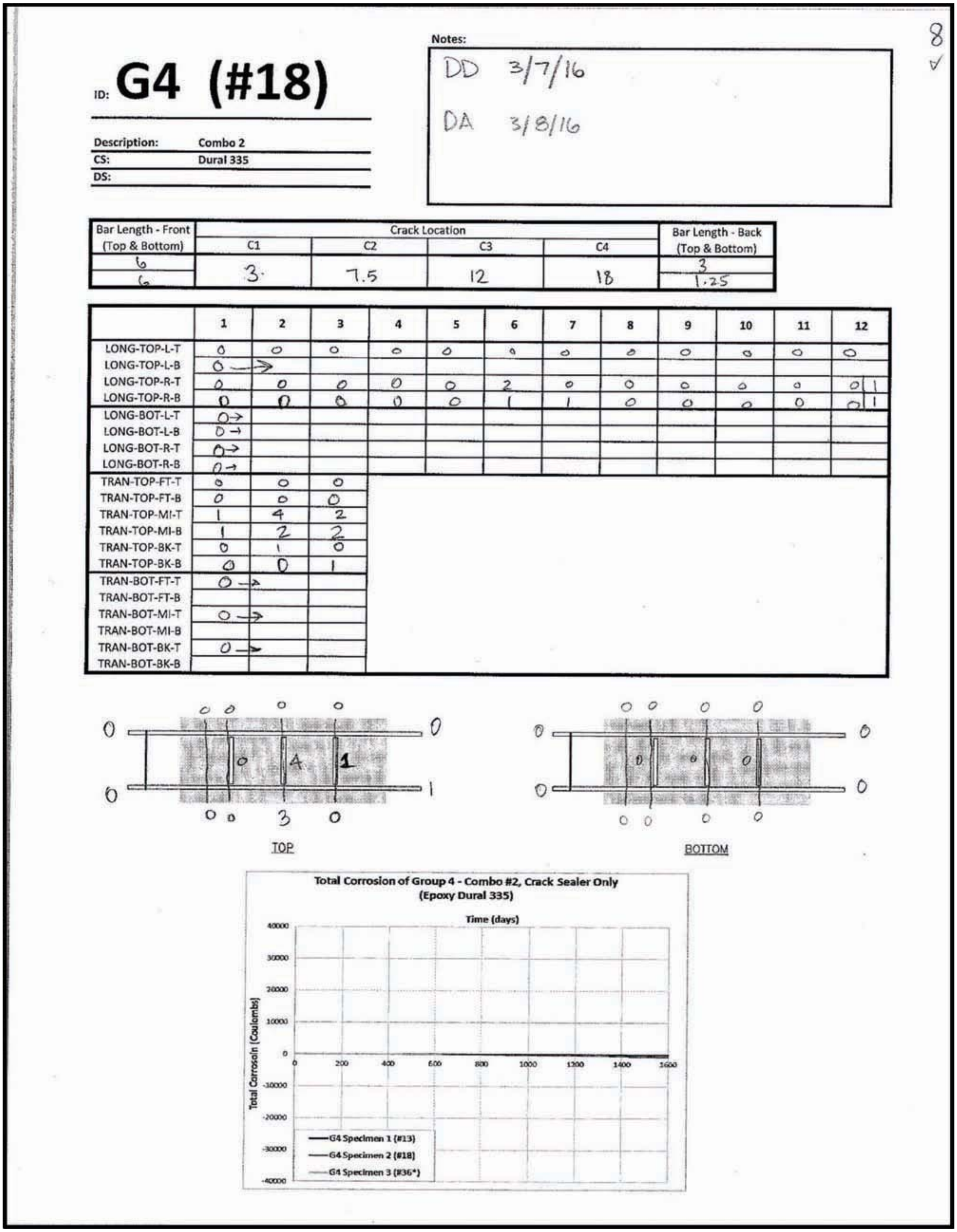
Description: Combo 2
CS: Dural 335
DS:

Notes:
DD: 3/5/16
DA: 3/8/16

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
6	6.5-5.5	13.5-13	18.5	—	3
6					1.25

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E2 0	0	0	0	0	2	2	0	0	0	0	0
LONG-TOP-L-B	E2 0	0	0	0	0	0	0	0	0	0	0	0
LONG-TOP-R-T	0	0	0	0	0	0	0	0	0	0	0	0
LONG-TOP-R-B	0	0	0	0	0	0	0	0	0	0	0	0
LONG-BOT-L-T	E2 0 →											
LONG-BOT-L-B	E2 ↓											
LONG-BOT-R-T												
LONG-BOT-R-B												
TRAN-TOP-FT-T	0	0	0									
TRAN-TOP-FT-B	0	0	0									
TRAN-TOP-MI-T	2	2	0									
TRAN-TOP-MI-B	1	0	0									
TRAN-TOP-BK-T	0	0	0									
TRAN-TOP-BK-B	0	0	0									
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.7 Autopsy notes for Specimen No. 13.



8 ✓

ID: **G4 (#18)**

Description: Combo 2
CS: Dural 335
DS:

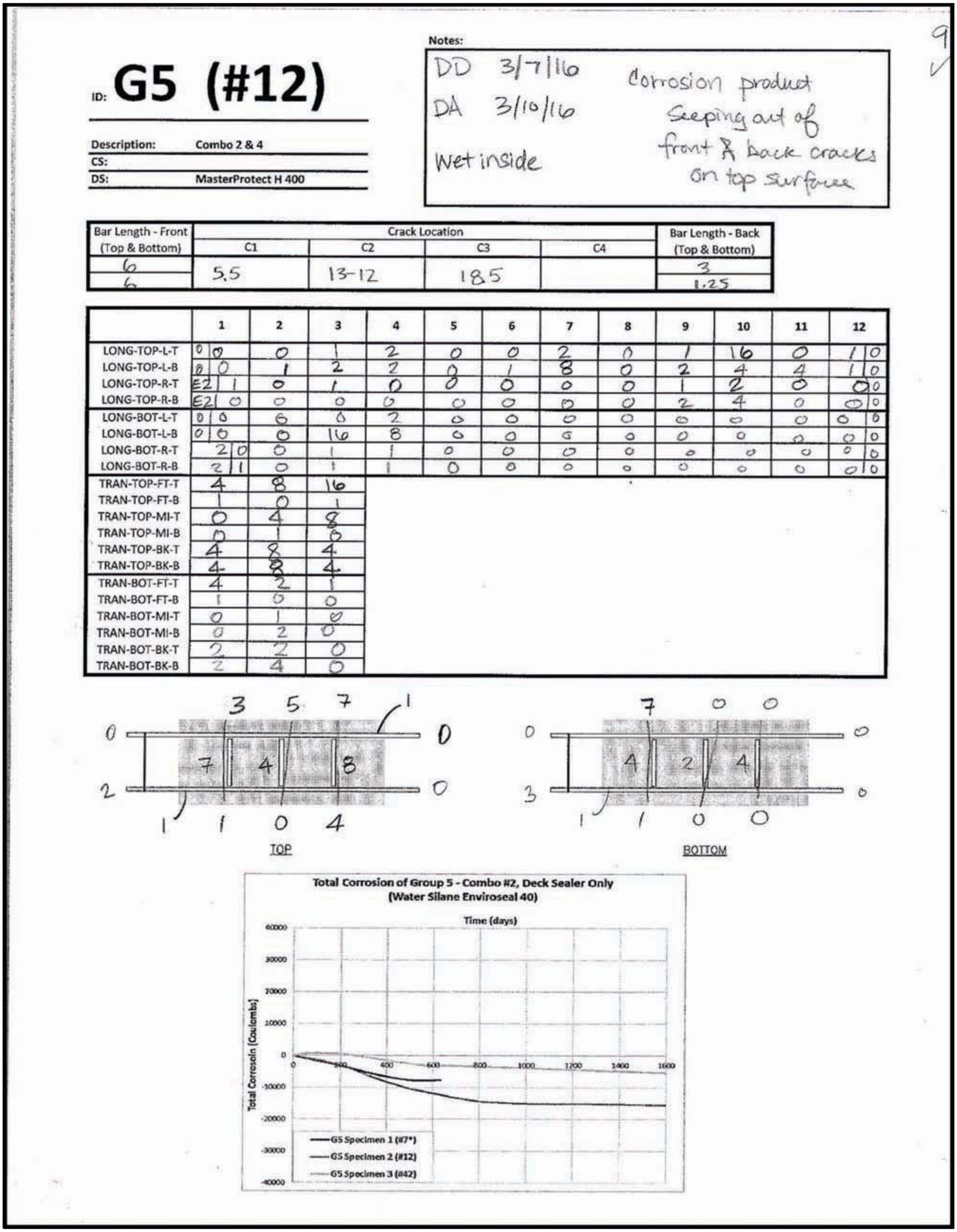
Notes:
DD 3/7/16
DA 3/8/16

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
6 6	3.	7.5	12	18	3 1.25

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0	0	0	0	0	0	0	0	0	0	0	0
LONG-TOP-L-B	0 →											
LONG-TOP-R-T	0	0	0	0	0	2	0	0	0	0	0	0 1
LONG-TOP-R-B	0	0	0	0	0	1	1	0	0	0	0	0 1
LONG-BOT-L-T	0 →											
LONG-BOT-L-B	0 →											
LONG-BOT-R-T	0 →											
LONG-BOT-R-B	0 →											
TRAN-TOP-FT-T	0	0	0									
TRAN-TOP-FT-B	0	0	0									
TRAN-TOP-MI-T	1	4	2									
TRAN-TOP-MI-B	1	2	2									
TRAN-TOP-BK-T	0	1	0									
TRAN-TOP-BK-B	0	0	1									
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B												
TRAN-BOT-MI-T	0 →											
TRAN-BOT-MI-B												
TRAN-BOT-BK-T	0 →											
TRAN-BOT-BK-B												

Total Corrosion of Group 4 - Combo #2, Crack Sealer Only (Epoxy Dural 335)

Figure C.8 Autopsy notes for Specimen No. 18.



9 ✓

ID: **G5 (#12)**

Description: Combo 2 & 4

CS:

DS: MasterProtect H 400

Notes:

DD 3/7/16

DA 3/10/16

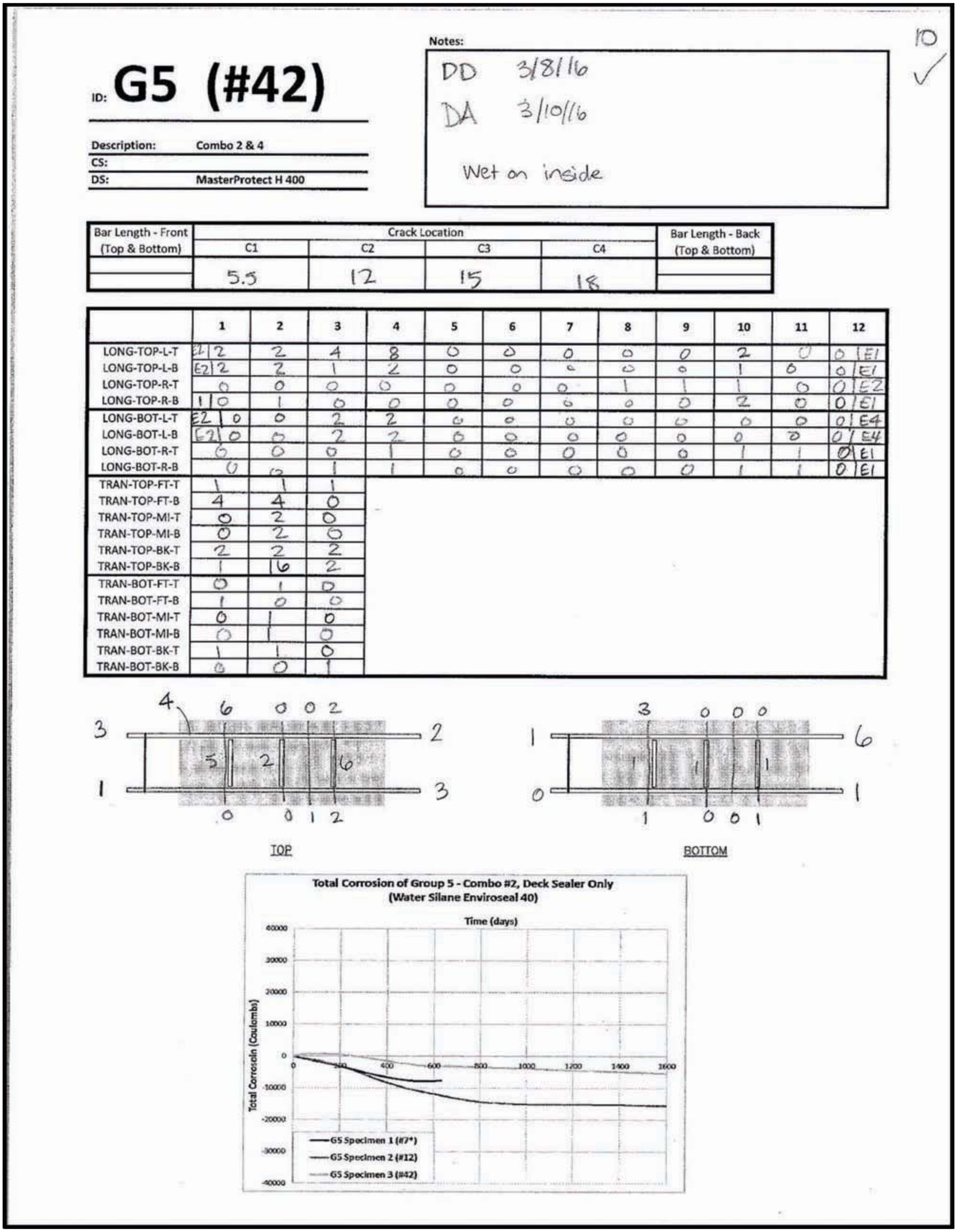
Wet inside

Corrosion product seeping out of front & back cracks on top surface

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
6	5.5	13-12	18.5		3
6					1.25

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0	0	1	2	0	0	2	0	1	16	0	1 0
LONG-TOP-L-B	0 0	1	2	2	0	1	8	0	2	4	4	1 0
LONG-TOP-R-T	E2 1	0	1	0	0	0	0	0	1	2	0	0 0
LONG-TOP-R-B	E2 0	0	0	0	0	0	0	0	2	4	0	0 0
LONG-BOT-L-T	0 0	6	0	2	0	0	0	0	0	0	0	0 0
LONG-BOT-L-B	0 0	0	16	8	0	0	6	0	0	0	0	0 0
LONG-BOT-R-T	2 0	0	1	1	0	0	0	0	0	0	0	0 0
LONG-BOT-R-B	2 1	0	1	1	0	0	0	0	0	0	0	0 0
TRAN-TOP-FT-T	4	8	16									
TRAN-TOP-FT-B	1	0	1									
TRAN-TOP-MI-T	0	4	8									
TRAN-TOP-MI-B	0	1	0									
TRAN-TOP-BK-T	4	8	4									
TRAN-TOP-BK-B	4	8	4									
TRAN-BOT-FT-T	4	2	1									
TRAN-BOT-FT-B	1	0	0									
TRAN-BOT-MI-T	0	1	0									
TRAN-BOT-MI-B	0	2	0									
TRAN-BOT-BK-T	2	2	0									
TRAN-BOT-BK-B	2	4	0									

Figure C.9 Autopsy notes for Specimen No. 12.



10 ✓

ID: **G5 (#42)**

Description: Combo 2 & 4
CS:
DS: MasterProtect H 400

Notes:
DD 3/8/16
DA 3/10/16

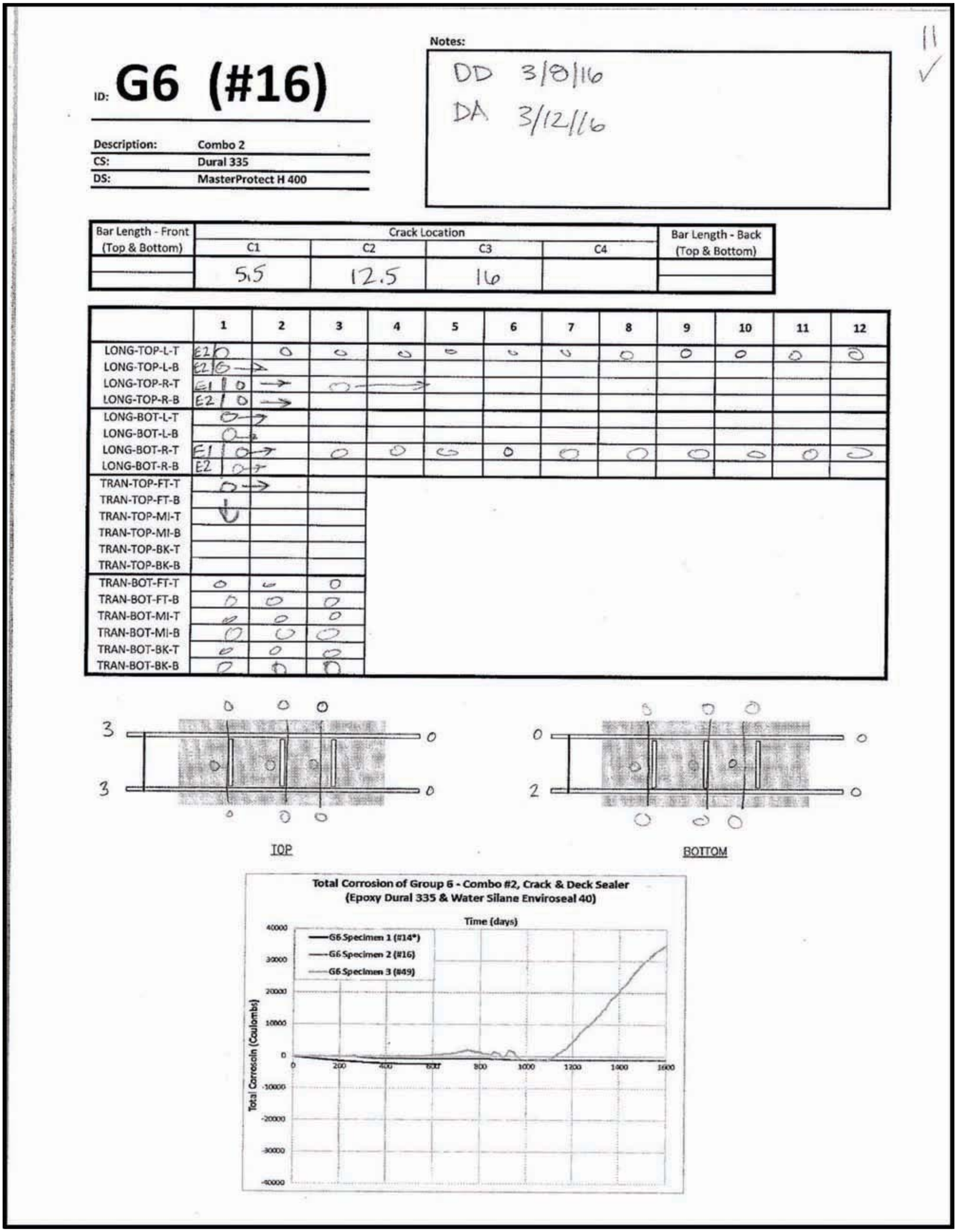
Wet on inside

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	5.5	12	15	18	

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E2 | 2	2	4	8	0	0	0	0	0	2	0	0 | E1
LONG-TOP-L-B	E2 | 2	2	1	2	0	0	0	0	0	1	0	0 | E1
LONG-TOP-R-T	0	0	0	0	0	0	0	1	1	1	0	0 | E2
LONG-TOP-R-B	1 | 0	1	0	0	0	0	0	0	0	2	0	0 | E1
LONG-BOT-L-T	E2 | 0	0	2	2	0	0	0	0	0	0	0	0 | E4
LONG-BOT-L-B	E2 | 0	0	2	2	0	0	0	0	0	0	0	0 | E4
LONG-BOT-R-T	0	0	0	1	0	0	0	0	0	1	1	0 | E1
LONG-BOT-R-B	0	0	1	1	0	0	0	0	0	1	1	0 | E1
TRAN-TOP-FT-T	1	1	1									
TRAN-TOP-FT-B	4	4	0									
TRAN-TOP-MI-T	0	2	0									
TRAN-TOP-MI-B	0	2	0									
TRAN-TOP-BK-T	2	2	2									
TRAN-TOP-BK-B	1	16	2									
TRAN-BOT-FT-T	0	1	0									
TRAN-BOT-FT-B	1	0	0									
TRAN-BOT-MI-T	0	1	0									
TRAN-BOT-MI-B	0	1	0									
TRAN-BOT-BK-T	1	1	0									
TRAN-BOT-BK-B	0	0	1									

Total Corrosion of Group 5 - Combo #2, Deck Sealer Only
(Water Silane Enviroseal 40)

Figure C.10 Autopsy notes for Specimen No. 42.



II ✓

ID: G6 (#16)

Description:	Combo 2
CS:	Dural 335
DS:	MasterProtect H 400

Notes:

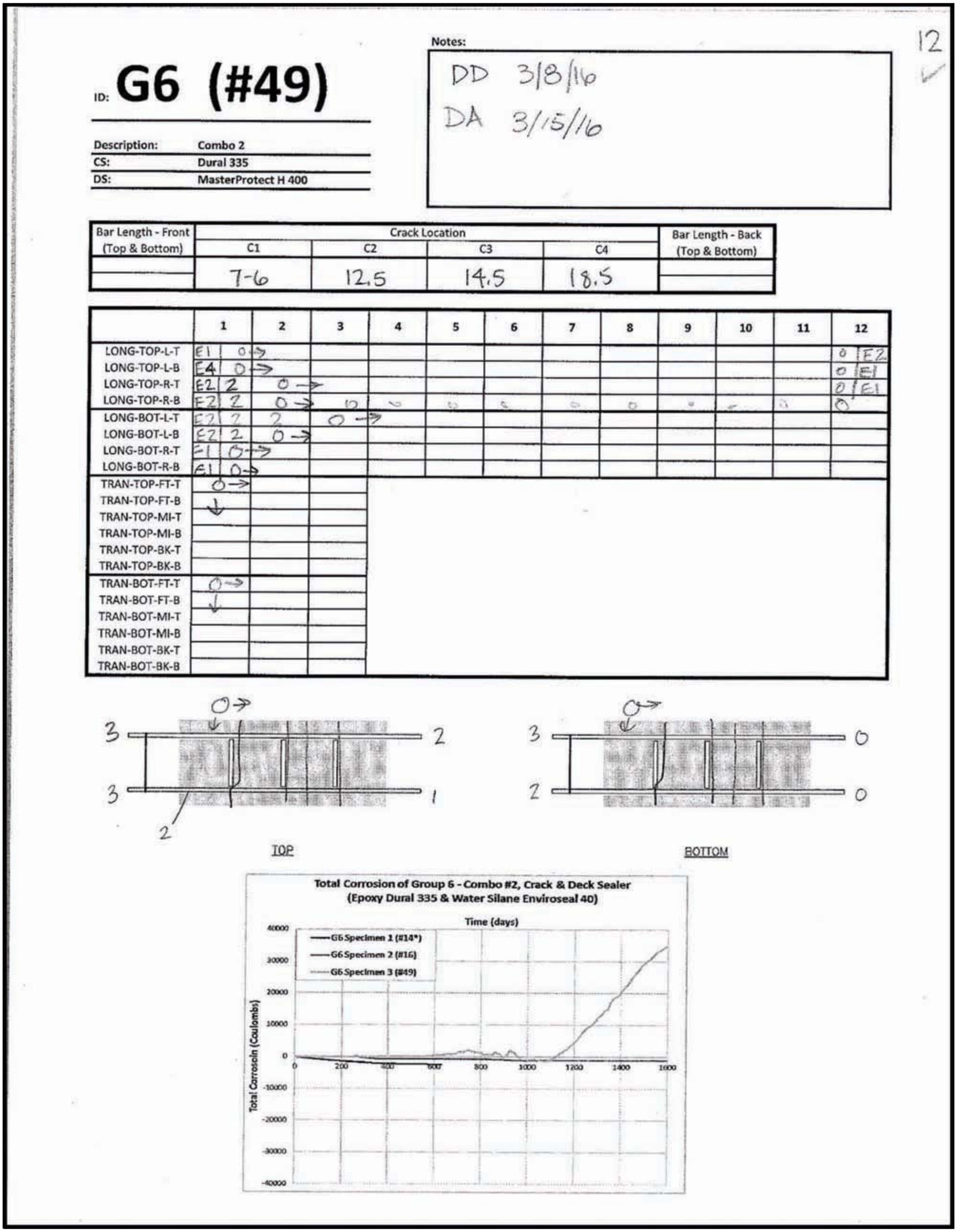
DD 3/8/16
DA 3/12/16

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	5.5	12.5	16		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E2 0	0	0	0	0	0	0	0	0	0	0	0
LONG-TOP-L-B	E2 0	→										
LONG-TOP-R-T	E1 0	→	0	→								
LONG-TOP-R-B	E2 0	→										
LONG-BOT-L-T	0	→										
LONG-BOT-L-B	0	→										
LONG-BOT-R-T	E1 0	→	0	0	0	0	0	0	0	0	0	0
LONG-BOT-R-B	E2 0	→										
TRAN-TOP-FT-T	0	→										
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0	0	0									
TRAN-BOT-FT-B	0	0	0									
TRAN-BOT-MI-T	0	0	0									
TRAN-BOT-MI-B	0	0	0									
TRAN-BOT-BK-T	0	0	0									
TRAN-BOT-BK-B	0	0	0									

Total Corrosion of Group 6 - Combo #2, Crack & Deck Sealer (Epoxy Dural 335 & Water Silane Enviroseal 40)

Figure C.11 Autopsy notes for Specimen No. 16.



12 ✓

ID: **G6 (#49)**

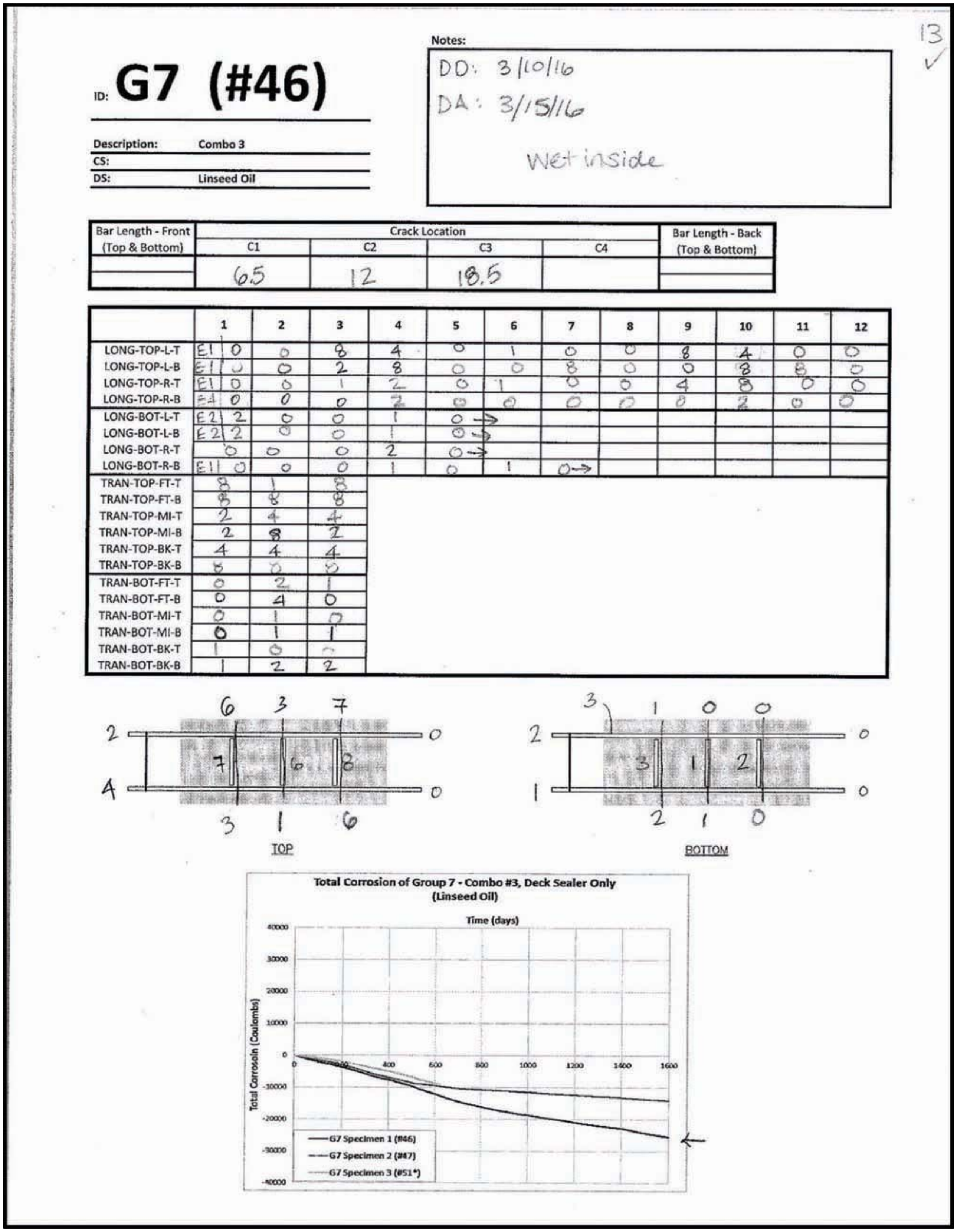
Description: Combo 2
CS: Dural 335
DS: MasterProtect H 400

Notes:
DD 3/8/16
DA 3/15/16

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	7-6	12.5	14.5	18.5	

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 0 →											0 E2
LONG-TOP-L-B	E4 0 →											0 E1
LONG-TOP-R-T	E2 2	0 →										0 E1
LONG-TOP-R-B	E2 2	0 →	0	0	0	0	0	0	0	0	0	0
LONG-BOT-L-T	E2 2	2	0 →									
LONG-BOT-L-B	E2 2	0 →										
LONG-BOT-R-T	E1 0 →											
LONG-BOT-R-B	E1 0 →											
TRAN-TOP-FT-T	0 →											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.12 Autopsy notes for Specimen No. 49.



13 ✓

ID: **G7 (#46)**

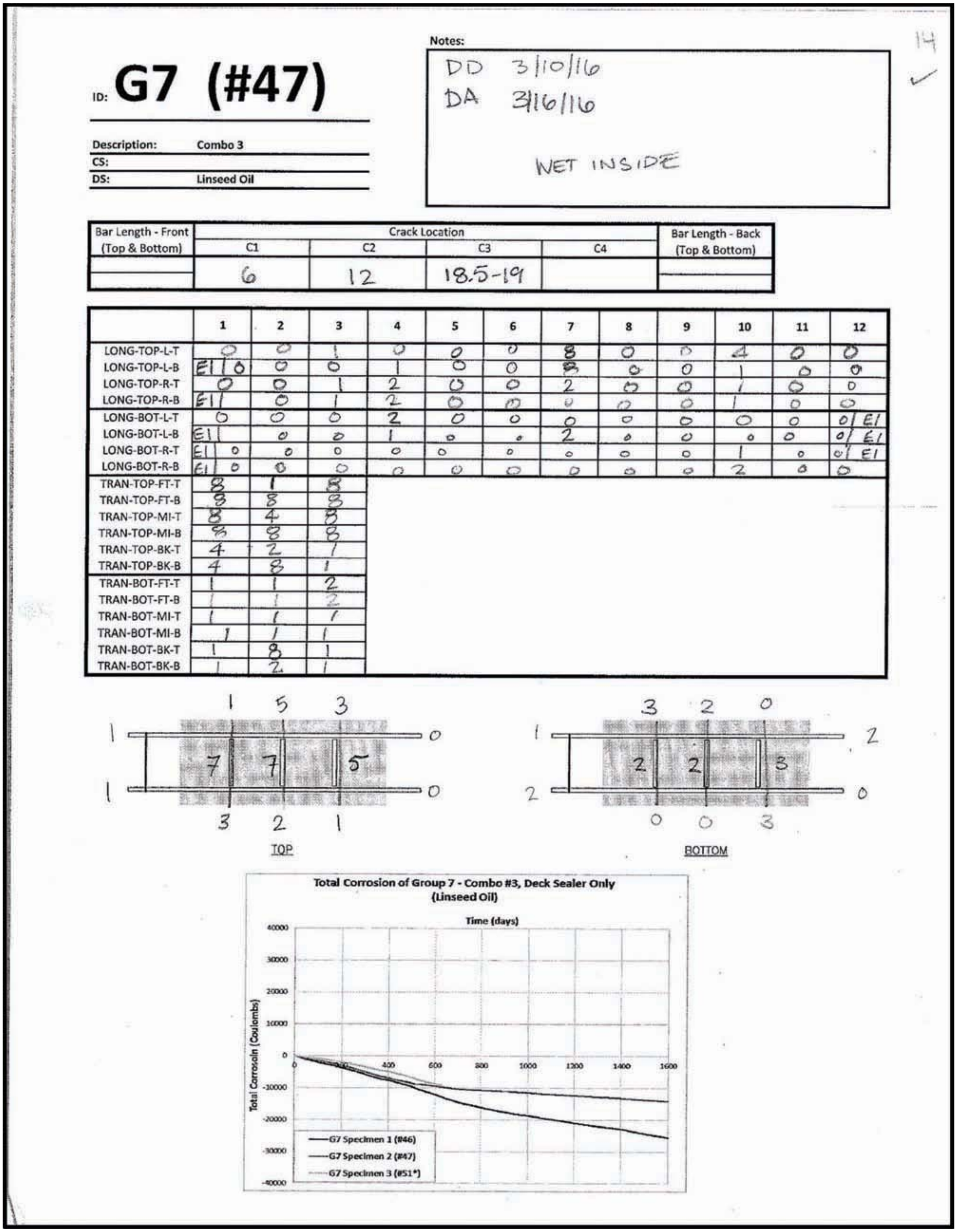
Description: Combo 3
CS:
DS: Linseed Oil

Notes:
DD: 3/10/16
DA: 3/15/16
Wet inside

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	6.5	12	18.5		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 0	0	8	4	0	1	0	0	8	4	0	0
LONG-TOP-L-B	E1 0	0	2	8	0	0	8	0	0	8	8	0
LONG-TOP-R-T	E1 0	0	1	2	0	1	0	0	4	8	0	0
LONG-TOP-R-B	E1 0	0	0	2	0	0	0	0	0	2	0	0
LONG-BOT-L-T	E2 2	0	0	1	0 →							
LONG-BOT-L-B	E2 2	0	0	1	0 →							
LONG-BOT-R-T	0	0	0	2	0 →							
LONG-BOT-R-B	E1 0	0	0	1	0	1	0 →					
TRAN-TOP-FT-T	8	1	8									
TRAN-TOP-FT-B	8	8	8									
TRAN-TOP-MI-T	2	4	4									
TRAN-TOP-MI-B	2	8	2									
TRAN-TOP-BK-T	4	4	4									
TRAN-TOP-BK-B	8	8	8									
TRAN-BOT-FT-T	0	2	1									
TRAN-BOT-FT-B	0	4	0									
TRAN-BOT-MI-T	0	1	0									
TRAN-BOT-MI-B	0	1	1									
TRAN-BOT-BK-T	1	0	0									
TRAN-BOT-BK-B	1	2	2									

Figure C.13 Autopsy notes for Specimen No. 46.



14

ID: **G7 (#47)**

Notes:
DD 3/10/16
DA 3/16/16

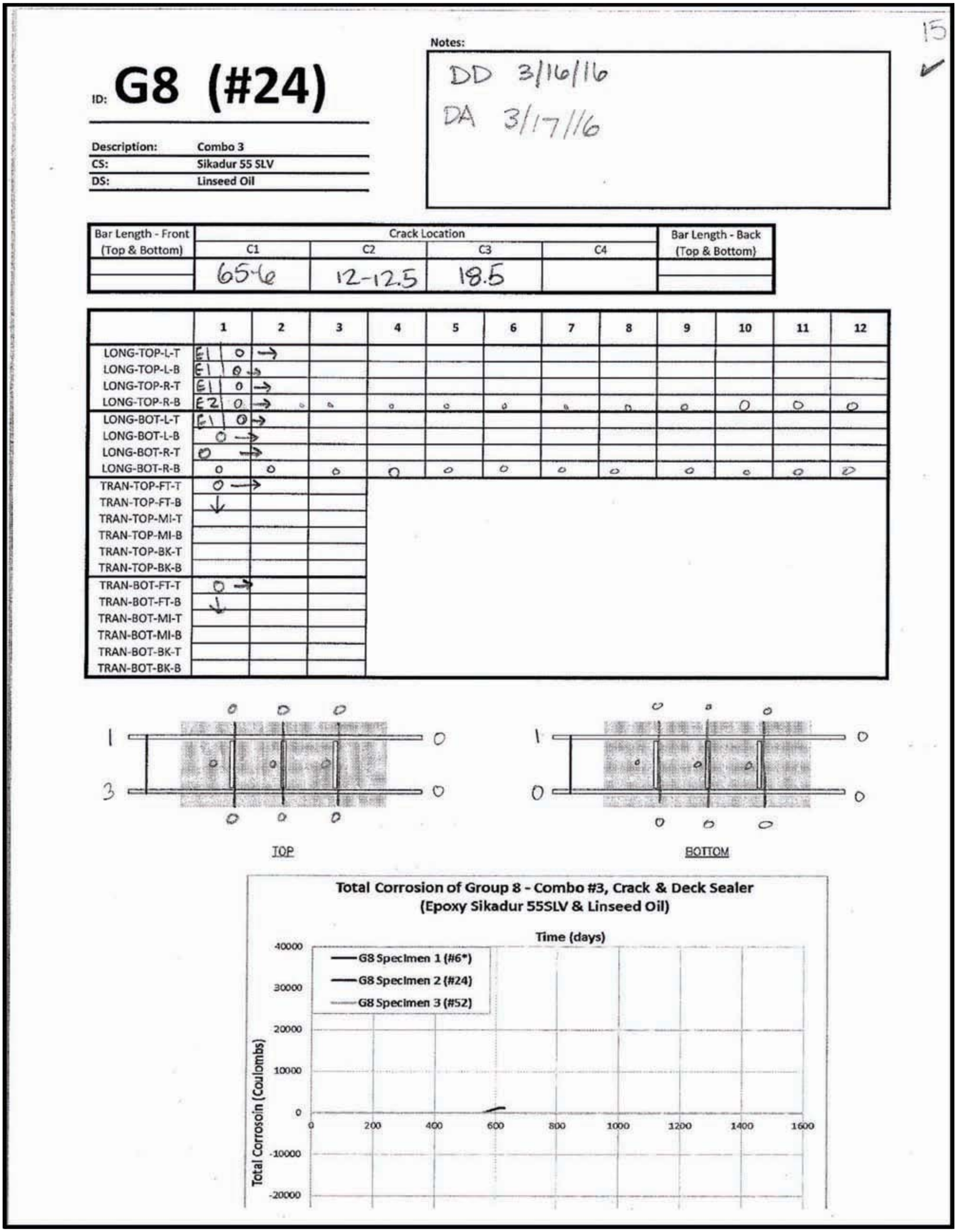
WET INSIDE

Description: Combo 3
CS:
DS: Linseed Oil

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	6	12	18.5-19		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0	0	1	0	0	0	8	0	0	4	0	0
LONG-TOP-L-B	E1 | 0	0	0	1	0	0	8	0	0	1	0	0
LONG-TOP-R-T	0	0	1	2	0	0	2	0	0	1	0	0
LONG-TOP-R-B	E1 |	0	1	2	0	0	0	0	0	1	0	0
LONG-BOT-L-T	0	0	0	2	0	0	0	0	0	0	0	0/ E1
LONG-BOT-L-B	E1 |	0	0	1	0	0	2	0	0	0	0	0/ E1
LONG-BOT-R-T	E1 | 0	0	0	0	0	0	0	0	0	1	0	0/ E1
LONG-BOT-R-B	E1 | 0	0	0	0	0	0	0	0	0	2	0	0
TRAN-TOP-FT-T	8	1	8									
TRAN-TOP-FT-B	8	8	8									
TRAN-TOP-MI-T	8	4	8									
TRAN-TOP-MI-B	8	8	8									
TRAN-TOP-BK-T	4	2	1									
TRAN-TOP-BK-B	4	8	1									
TRAN-BOT-FT-T	1	1	2									
TRAN-BOT-FT-B	1	1	2									
TRAN-BOT-MI-T	1	1	1									
TRAN-BOT-MI-B	1	1	1									
TRAN-BOT-BK-T	1	8	1									
TRAN-BOT-BK-B	1	2	1									

Figure C.14 Autopsy notes for Specimen No. 47.



15 ✓

ID: **G8 (#24)**

Notes:

DD 3/16/16
DA 3/17/16

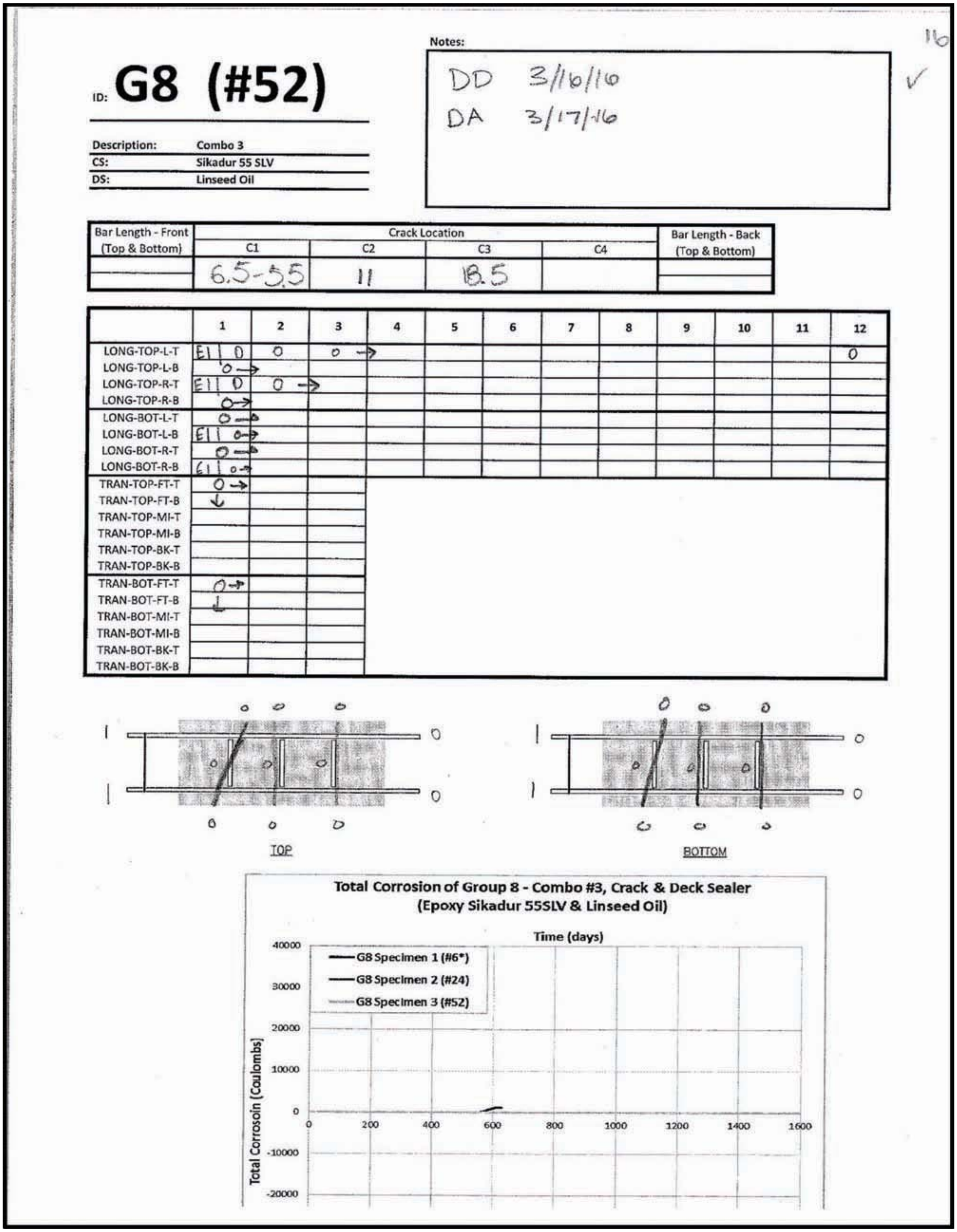
Description:	Combo 3
CS:	Sikadur 55 SLV
DS:	Linseed Oil

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	65-6	12-12.5	18.5		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 0	→										
LONG-TOP-L-B	E1 0	→										
LONG-TOP-R-T	E1 0	→										
LONG-TOP-R-B	E2 0	→ 0	0	0	0	0	0	0	0	0	0	0
LONG-BOT-L-T	E1 0	→										
LONG-BOT-L-B	0	→										
LONG-BOT-R-T	0	→										
LONG-BOT-R-B	0	0	0	0	0	0	0	0	0	0	0	0
TRAN-TOP-FT-T	0	→										
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0	→										
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Total Corrosion of Group 8 - Combo #3, Crack & Deck Sealer
(Epoxy Sikadur 55SLV & Linseed Oil)

Figure C.15 Autopsy notes for Specimen No. 24.



116
✓

ID: **G8 (#52)**

Description: Combo 3
CS: Sikadur 55 SLV
DS: Linseed Oil

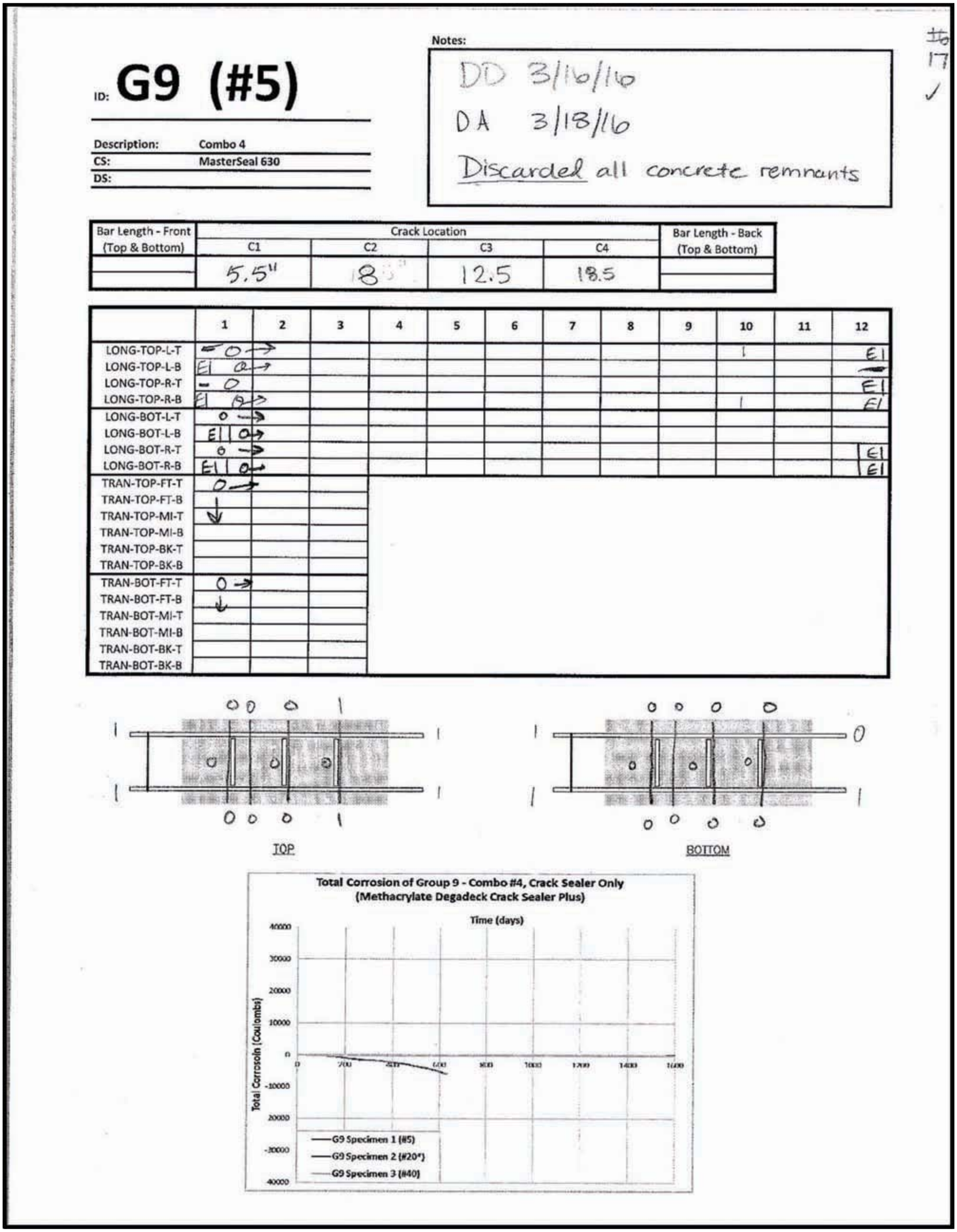
Notes:
DD 3/16/16
DA 3/17/16

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	6.5-5.5	11	18.5		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 | 0	0	0 →									0
LONG-TOP-L-B	0 →											
LONG-TOP-R-T	E1 | 0	0 →										
LONG-TOP-R-B	0 →											
LONG-BOT-L-T	0 →											
LONG-BOT-L-B	E1 | 0 →											
LONG-BOT-R-T	0 →											
LONG-BOT-R-B	E1 | 0 →											
TRAN-TOP-FT-T	0 →											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Total Corrosion of Group 8 - Combo #3, Crack & Deck Sealer
(Epoxy Sikadur 55SLV & Linseed Oil)

Figure C.16 Autopsy notes for Specimen No. 52.



ID: **G9 (#5)**

Description: Combo 4
CS: MasterSeal 630
DS:

Notes:

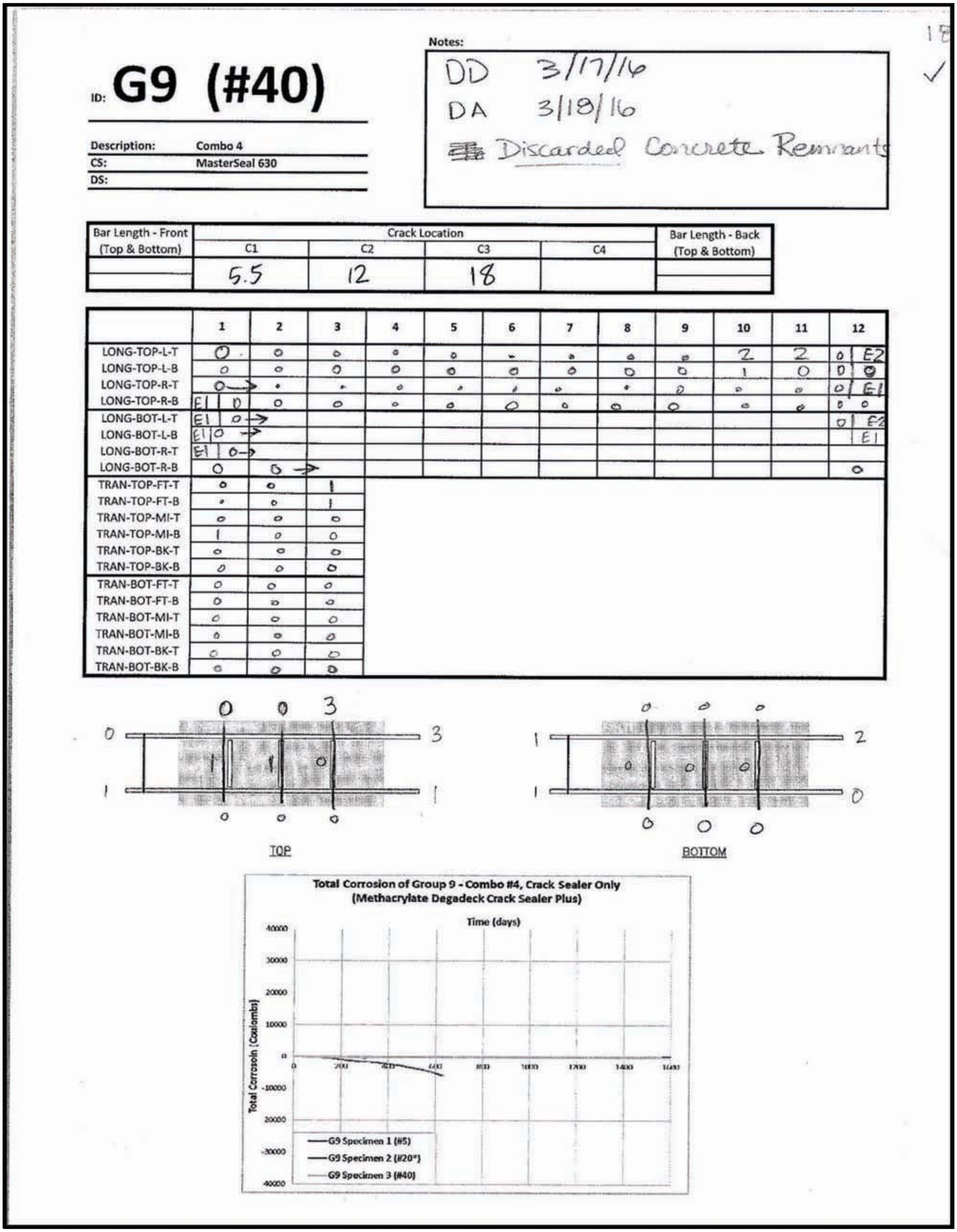
DD 3/16/16
DA 3/18/16
Discarded all concrete remnants

#5
17
✓

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	5.5"	8.5"	12.5	18.5	

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	— O	→								|		E|
LONG-TOP-L-B	E| O	→										—
LONG-TOP-R-T	— O											E|
LONG-TOP-R-B	E| O	→								|		E|
LONG-BOT-L-T	O	→										
LONG-BOT-L-B	E| |	O→										
LONG-BOT-R-T	O	→										E|
LONG-BOT-R-B	E| |	O→										E|
TRAN-TOP-FT-T	O	→										
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T	↓											
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	O	→										
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.17 Autopsy notes for Specimen No. 5.



18
✓

ID: **G9 (#40)**

Description:	Combo 4
CS:	MasterSeal 630
DS:	

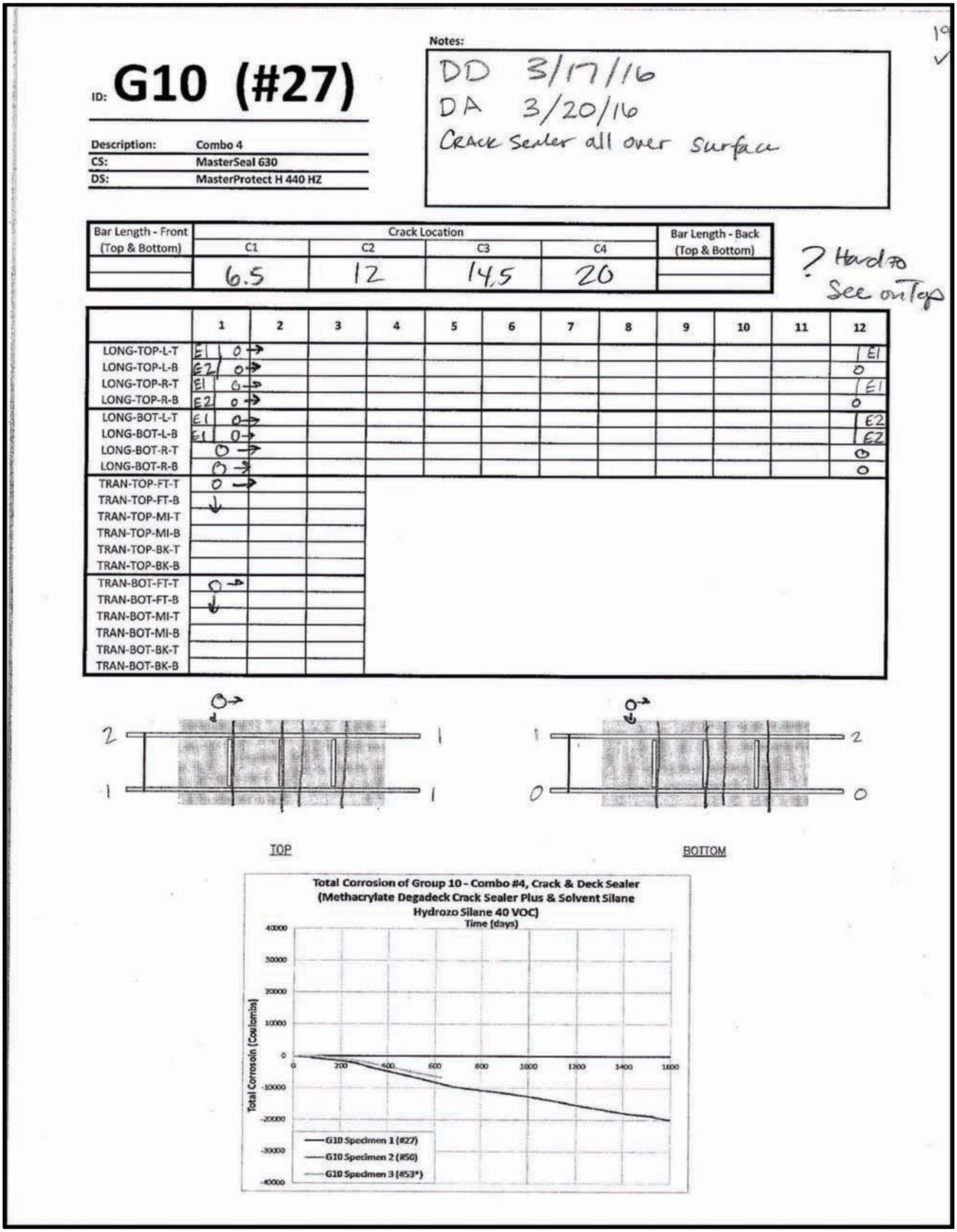
Notes:
DD 3/17/16
DA 3/18/16
Discarded Concrete Remnants

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	5.5	12	18		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0	0	0	0	0	-	0	0	0	2	2	0 E2
LONG-TOP-L-B	0	0	0	0	0	0	0	0	0	1	0	0 0
LONG-TOP-R-T	0→	•	•	0	0	/	0	•	0	0	0	0 E1
LONG-TOP-R-B	E1 0	0	0	0	0	0	0	0	0	0	0	0 0
LONG-BOT-L-T	E1 0→											0 E2
LONG-BOT-L-B	E1 0 →											E1
LONG-BOT-R-T	E1 0→											
LONG-BOT-R-B	0	0 →										0
TRAN-TOP-FT-T	0	0	1									
TRAN-TOP-FT-B	•	0	1									
TRAN-TOP-MI-T	0	0	0									
TRAN-TOP-MI-B	1	0	0									
TRAN-TOP-BK-T	0	0	0									
TRAN-TOP-BK-B	0	0	0									
TRAN-BOT-FT-T	0	0	0									
TRAN-BOT-FT-B	0	0	0									
TRAN-BOT-MI-T	0	0	0									
TRAN-BOT-MI-B	0	0	0									
TRAN-BOT-BK-T	0	0	0									
TRAN-BOT-BK-B	0	0	0									

Total Corrosion of Group 9 - Combo #4, Crack Sealer Only
(Methacrylate Degadeck Crack Sealer Plus)

Figure C.18 Autopsy notes for Specimen No. 40.



19 ✓

ID: **G10 (#27)**

Description:	Combo 4
CS:	MasterSeal 630
DS:	MasterProtect H 440 HZ

Notes:

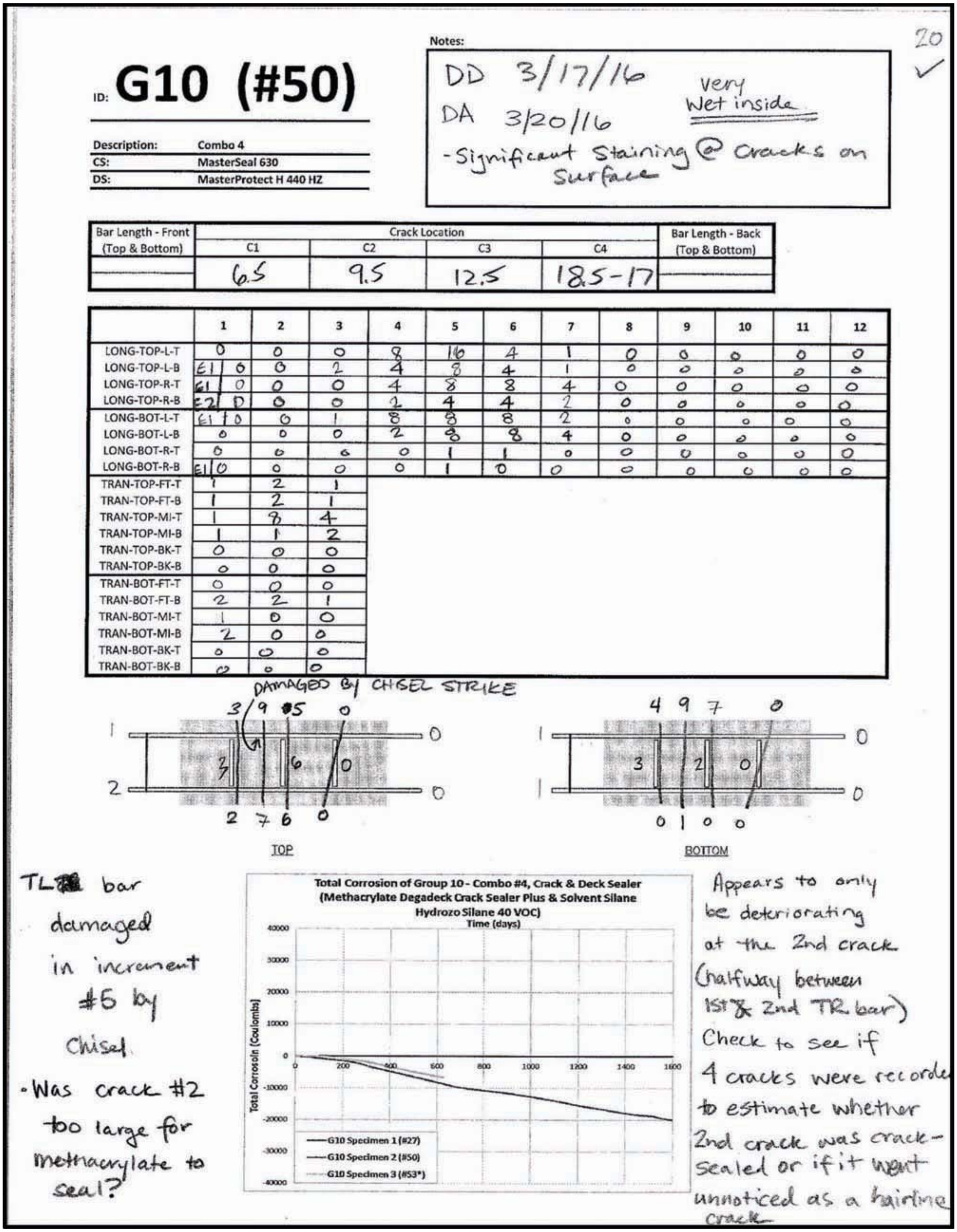
DD 3/17/16
DA 3/20/16
Crack Sealer all over surface

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	6.5	12	14.5	20	

? Hard to See on Top

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 0 →											E1
LONG-TOP-L-B	E2 0 →											0
LONG-TOP-R-T	E1 0 →											E1
LONG-TOP-R-B	E2 0 →											0
LONG-BOT-L-T	E1 0 →											E2
LONG-BOT-L-B	E1 0 →											E2
LONG-BOT-R-T	0 →											0
LONG-BOT-R-B	0 →											0
TRAN-TOP-FT-T	0 →											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.19 Autopsy notes for Specimen No. 27.



20 ✓

ID: **G10 (#50)**

Description: Combo 4
CS: MasterSeal 630
DS: MasterProtect H 440 HZ

Notes:
DD 3/17/16
DA 3/20/16
very Wet inside
-Significant Staining @ Cracks on Surface

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	6.5	9.5	12.5	18.5-17	

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0	0	0	8	16	4	1	0	0	0	0	0
LONG-TOP-L-B	E1 0	0	2	4	8	4	1	0	0	0	0	0
LONG-TOP-R-T	E1 0	0	0	4	8	8	4	0	0	0	0	0
LONG-TOP-R-B	E2 0	0	0	2	4	4	2	0	0	0	0	0
LONG-BOT-L-T	E1 0	0	1	8	8	8	2	0	0	0	0	0
LONG-BOT-L-B	0	0	0	2	8	8	4	0	0	0	0	0
LONG-BOT-R-T	0	0	0	0	1	1	0	0	0	0	0	0
LONG-BOT-R-B	E1 0	0	0	0	1	0	0	0	0	0	0	0
TRAN-TOP-FT-T	1	2	1									
TRAN-TOP-FT-B	1	2	1									
TRAN-TOP-MI-T	1	8	4									
TRAN-TOP-MI-B	1	1	2									
TRAN-TOP-BK-T	0	0	0									
TRAN-TOP-BK-B	0	0	0									
TRAN-BOT-FT-T	0	0	0									
TRAN-BOT-FT-B	2	2	1									
TRAN-BOT-MI-T	1	0	0									
TRAN-BOT-MI-B	2	0	0									
TRAN-BOT-BK-T	0	0	0									
TRAN-BOT-BK-B	0	0	0									

DAMAGED BY CHISEL STRIKE

3/9 #5 0
1 0
2 0
3/7 6 0
2 7 6 0

4 9 7 0
1 0
1 0
3 2 0
0 1 0 0

TOP

BOTTOM

TL bar damaged in increment #5 by Chisel.

• Was crack #2 too large for methacrylate to seal?

Total Corrosion of Group 10 - Combo #4, Crack & Deck Sealer (Methacrylate Degadeck Crack Sealer Plus & Solvent Silane Hydrozo Silane 40 VOC)

Time (days)

Total Corrosoin (Coulombs)

40000
30000
20000
10000
0
-10000
-20000
-30000
-40000

0 200 400 600 800 1000 1200 1400 1600

G10 Specimen 1 (#27)
G10 Specimen 2 (#50)
G10 Specimen 3 (#53*)

Appears to only be deteriorating at the 2nd crack (halfway between 1st & 2nd TR bar)

Check to see if 4 cracks were recorded to estimate whether 2nd crack was crack-sealed or if it went unnoticed as a hairline crack

Figure C.20 Autopsy notes for Specimen No. 50.

ID: **G11 (#22)**

21

0

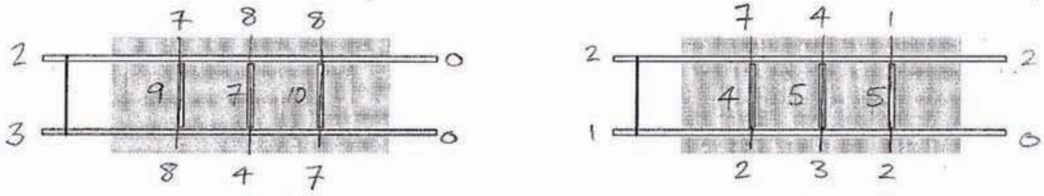
Notes:

DD 6/27/16
DA 6/27/16

Description: Resealed Control
CS:
DS: Reseal: MasterProtect H 400

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	6	12	18		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	1 1	0	1	8	2	2	4	2	2	8	4	1 0
LONG-TOP-L-B	0 2	0	2	8	8	16	4	0	2	8	16	1 0
LONG-TOP-R-T	1 2	0	2	16	2	2	1	2	4	4	2	0 0
LONG-TOP-R-B	1 2	0	1	4	2	4	2	0	8	4	1	0 0
LONG-BOT-L-T	2 2	1	2	4	1	0	1	1	0	1	0	0 1
LONG-BOT-L-B	1 4	8	8	0	0	0	2	2	0	1	0	0 2
LONG-BOT-R-T	0 0	0	1	1	0	0	2	0	1	1	0	0 0
LONG-BOT-R-B	1 2	0	0	2	0	1	2	0	0	1	0	0 0
TRAN-TOP-FT-T	8	16	16									
TRAN-TOP-FT-B	8	8	8									
TRAN-TOP-MI-T	8	4	4									
TRAN-TOP-MI-B	8	4	4									
TRAN-TOP-BK-T	8	16	16									
TRAN-TOP-BK-B	16	16	16									
TRAN-BOT-FT-T	1	1	4									
TRAN-BOT-FT-B	4	1	4									
TRAN-BOT-MI-T	2	8	4									
TRAN-BOT-MI-B	1	4	8									
TRAN-BOT-BK-T	1	8	2									
TRAN-BOT-BK-B	2	4	2									



TOP

BOTTOM

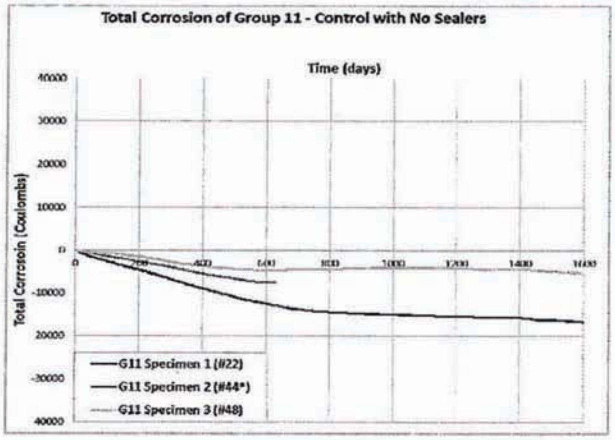


Figure C.21 Autopsy notes for Specimen No. 22.

22

✓

ID: G11 (#48)

Description: Control

CS:

DS:

Notes:

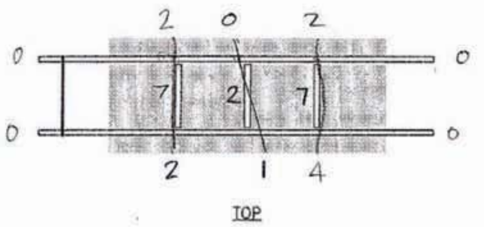
DD 3/20/16

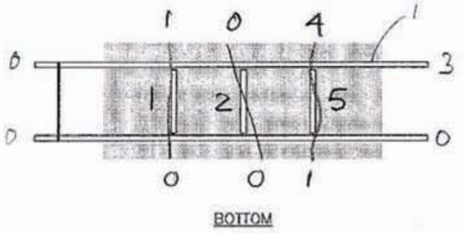
DA 3/21/16

- Staining on top surface @ crack 3
- Salt deposits on all sides

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	5.5	11-13	18		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0	0	1	2	0	0	0	0	0	2	0	0
LONG-TOP-L-B	0	0	1	1	0	0	0	0	1	1	0	0
LONG-TOP-R-T	0	0	2	1	0	0	1	0	1	2	0	0
LONG-TOP-R-B	0	0	1	1	0	0	0	0	2	1	0	0
LONG-BOT-L-T	0	0	0	1	0	0	0	0	2	0	0	1 / E2
LONG-BOT-L-B	0	0	0	1	0	0	0	0	1	2	1	1 / E2
LONG-BOT-R-T	0	0	0	0	0	0	0	0	0	1	0	0
LONG-BOT-R-B	0	0	0	0	0	0	0	0	0	1	0	0
TRAN-TOP-FT-T	4	8	8									
TRAN-TOP-FT-B	4	8	2									
TRAN-TOP-MI-T	1	1	0									
TRAN-TOP-MI-B	2	1	0									
TRAN-TOP-BK-T	2	1	8									
TRAN-TOP-BK-B	8	8	8									
TRAN-BOT-FT-T	0	1	1									
TRAN-BOT-FT-B	1	1	1									
TRAN-BOT-MI-T	1	0	2									
TRAN-BOT-MI-B	1	0	2									
TRAN-BOT-BK-T	1	8	8									
TRAN-BOT-BK-B	4	1	1									





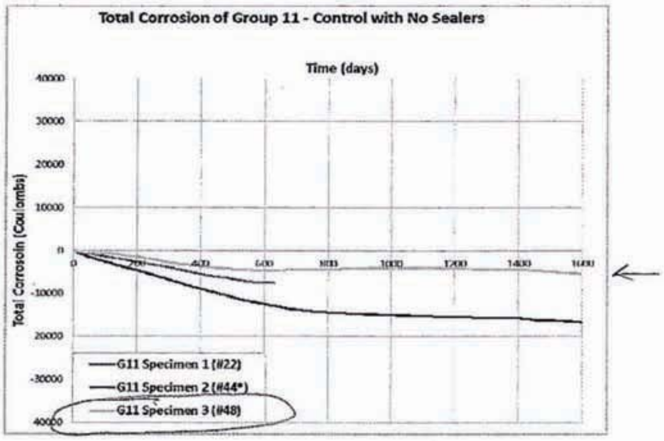
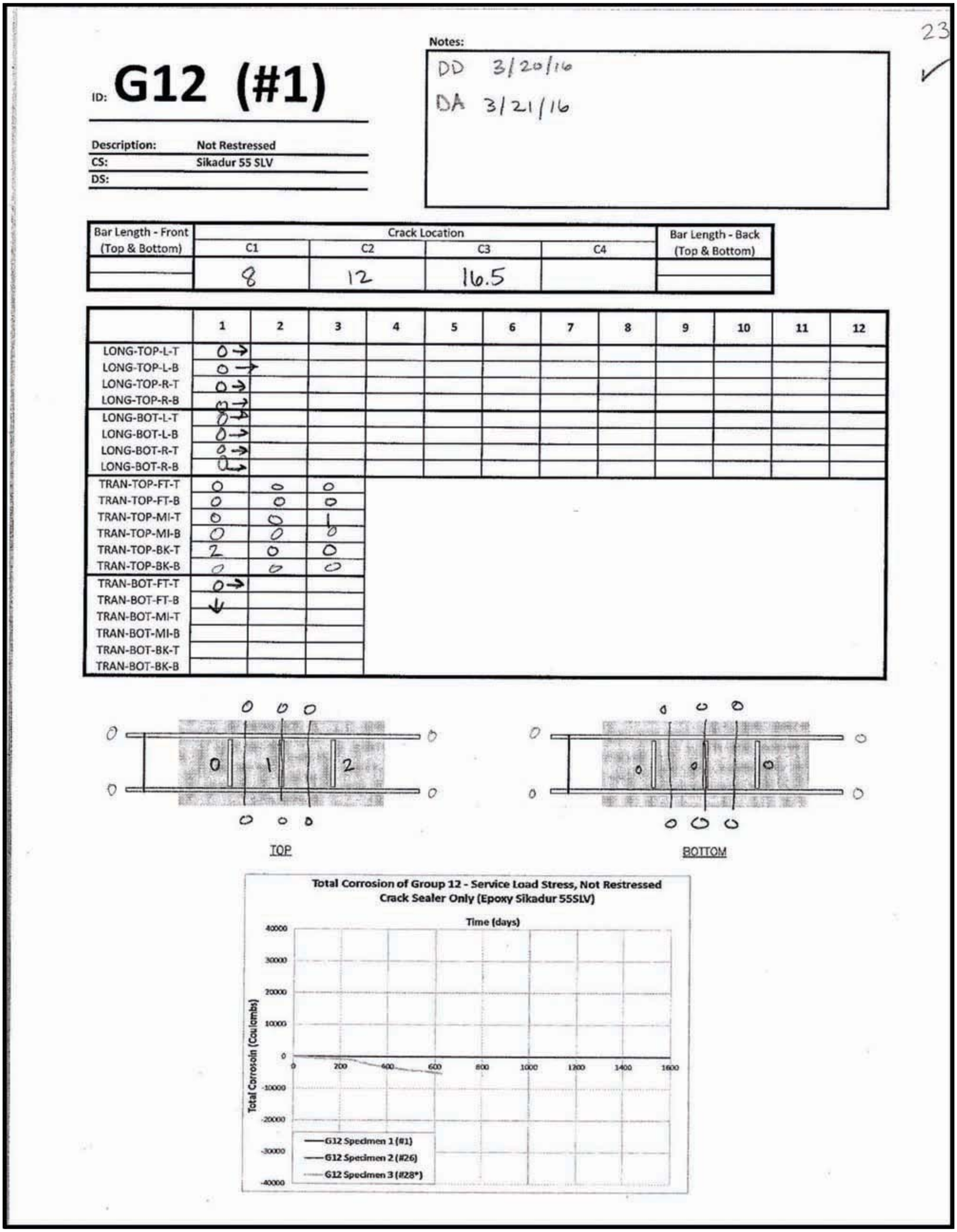


Figure C.22 Autopsy notes for Specimen No. 48.



23 ✓

ID: G12 (#1)

Description: Not Restressed

CS: Sikadur 55 SLV

DS:

Notes:

DD 3/20/16

DA 3/21/16

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	8	12	16.5		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 →											
LONG-TOP-L-B	0 →											
LONG-TOP-R-T	0 →											
LONG-TOP-R-B	0 →											
LONG-BOT-L-T	0 →											
LONG-BOT-L-B	0 →											
LONG-BOT-R-T	0 →											
LONG-BOT-R-B	0 →											
TRAN-TOP-FT-T	0	0	0									
TRAN-TOP-FT-B	0	0	0									
TRAN-TOP-MI-T	0	0	1									
TRAN-TOP-MI-B	0	0	0									
TRAN-TOP-BK-T	2	0	0									
TRAN-TOP-BK-B	0	0	0									
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Total Corrosion of Group 12 - Service Load Stress, Not Restressed
Crack Sealer Only (Epoxy Sikadur 55SLV)

Figure C.23 Autopsy notes for Specimen No. 1.

24
✓

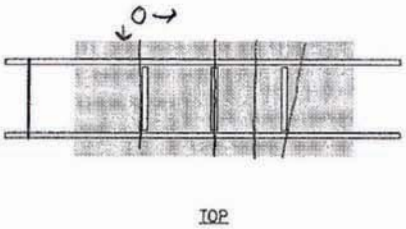
ID: **G12 (#26)**

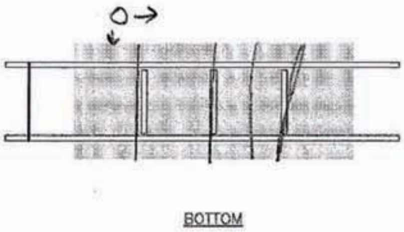
Description: Not Restressed
CS: Sikadur 55 SLV
DS:

Notes:
DD 3/20/16
DA 3/21/16

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	5.5	12	16	19-18	

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 →											
LONG-TOP-L-B	↓											
LONG-TOP-R-T												
LONG-TOP-R-B												
LONG-BOT-L-T												
LONG-BOT-L-B												
LONG-BOT-R-T												
LONG-BOT-R-B												
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												





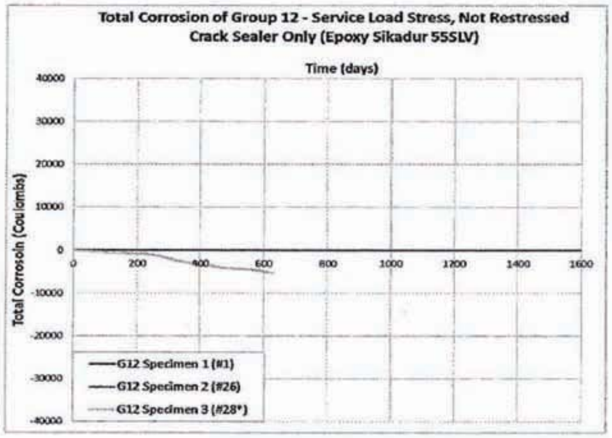
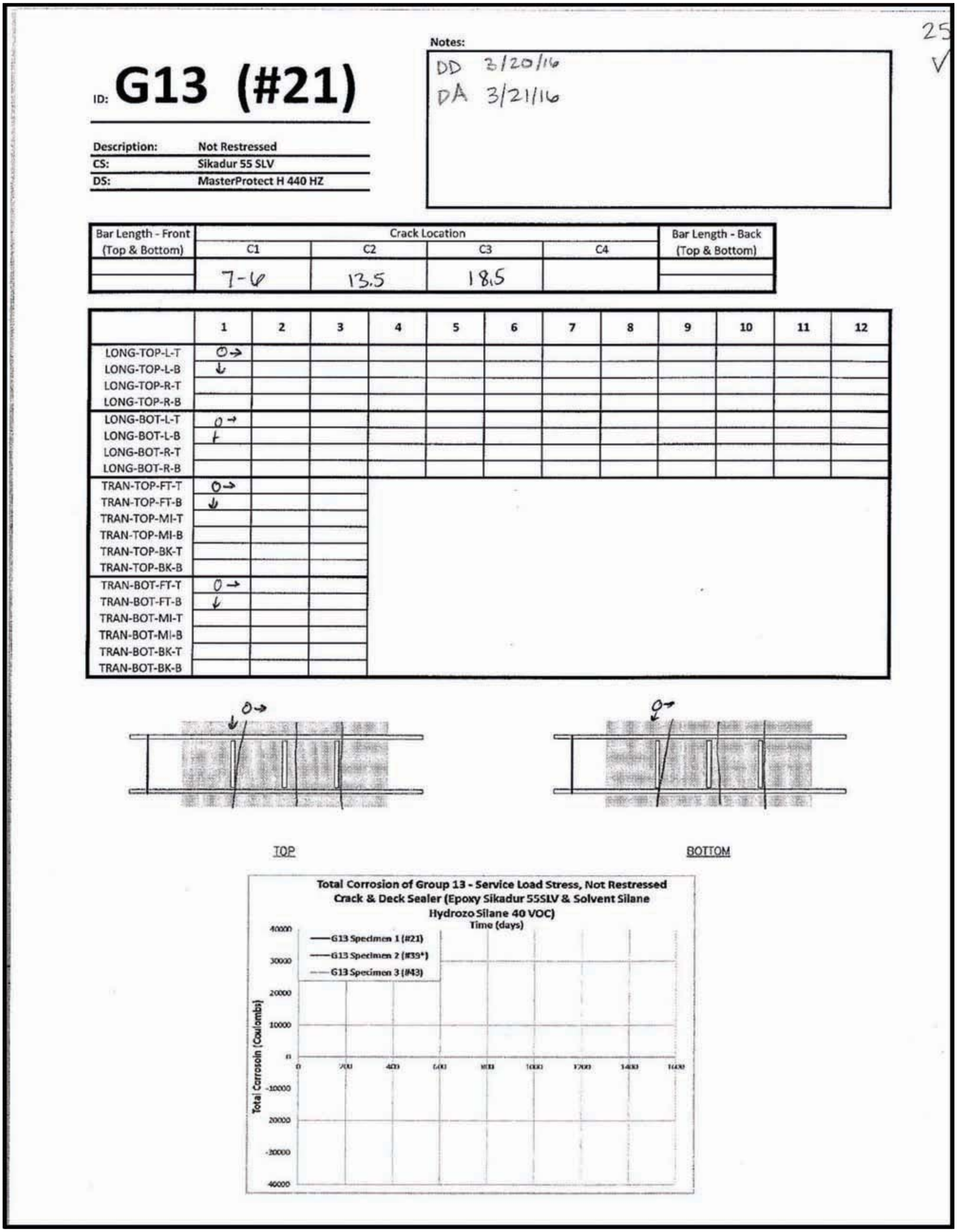


Figure C.24 Autopsy notes for Specimen No. 26.



25
✓

ID: **G13 (#21)**

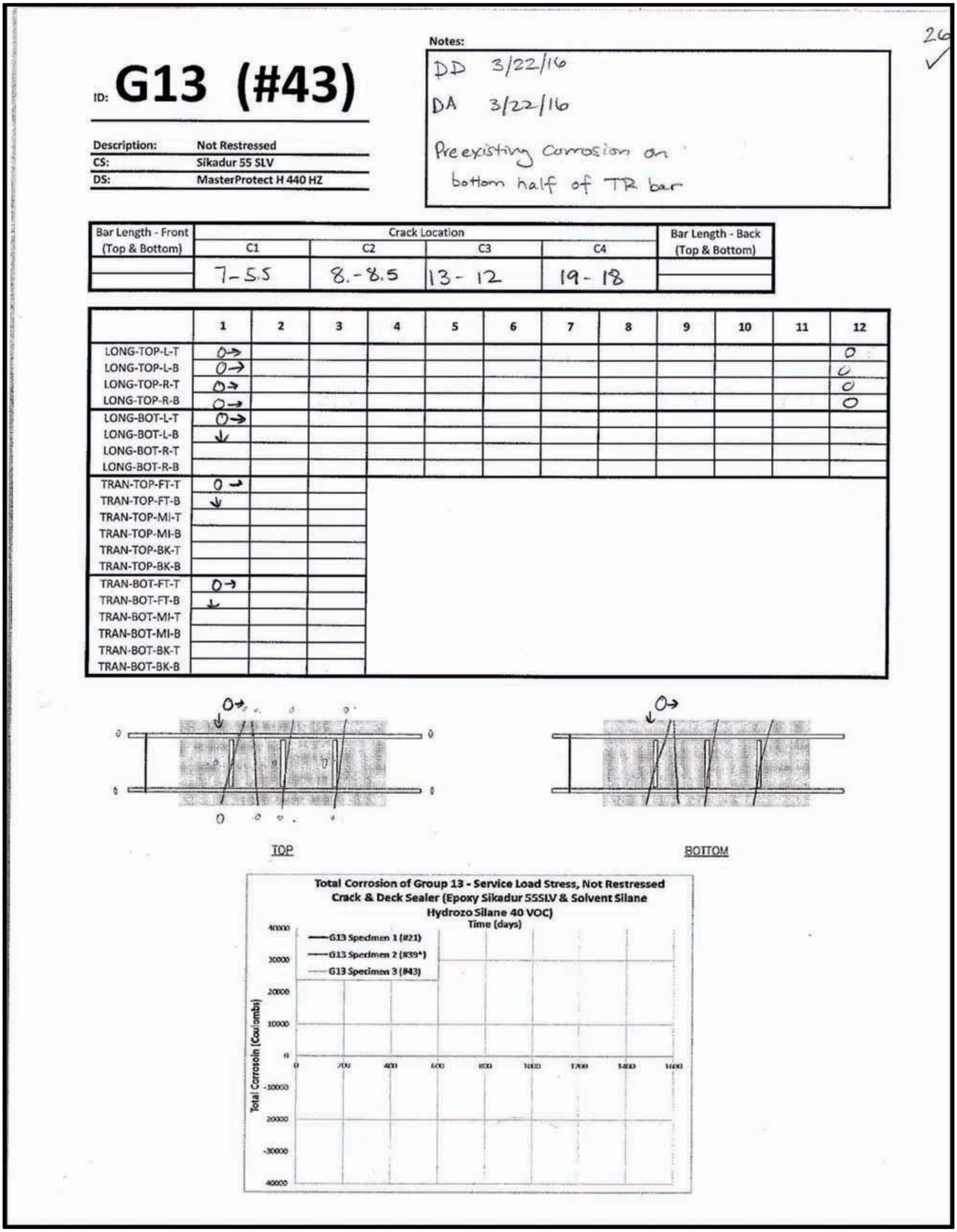
Notes:
DD 3/20/16
DA 3/21/16

Description:	Not Restressed
CS:	Sikadur 55 SLV
DS:	MasterProtect H 440 HZ

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	7-6	13.5	18.5		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 →											
LONG-TOP-L-B	↓											
LONG-TOP-R-T												
LONG-TOP-R-B												
LONG-BOT-L-T	0 →											
LONG-BOT-L-B	↓											
LONG-BOT-R-T												
LONG-BOT-R-B												
TRAN-TOP-FT-T	0 →											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.25 Autopsy notes for Specimen No. 21.



26 ✓

ID: **G13 (#43)**

Description:	Not Restressed
CS:	Sikadur 55 SLV
DS:	MasterProtect H 440 HZ

Notes:

DD 3/22/16

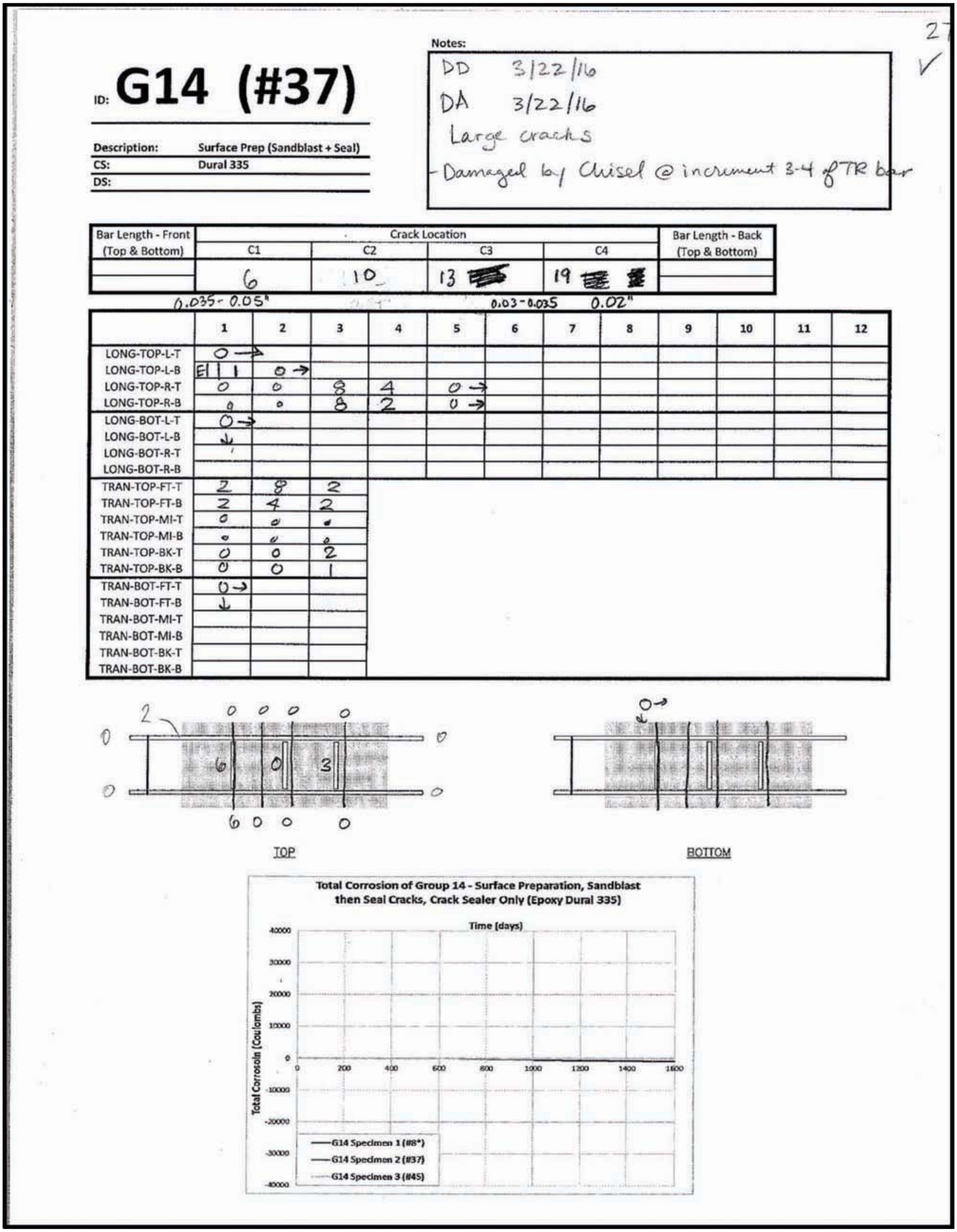
DA 3/22/16

Preexisting corrosion on bottom half of TR bar

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	7-5.5	8.-8.5	13-12	19-18	

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0→											0
LONG-TOP-L-B	0→											0
LONG-TOP-R-T	0→											0
LONG-TOP-R-B	0→											0
LONG-BOT-L-T	0→											
LONG-BOT-L-B	↓											
LONG-BOT-R-T												
LONG-BOT-R-B												
TRAN-TOP-FT-T	0→											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0→											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.26 Autopsy notes for Specimen No. 43.



27

✓

ID: **G14 (#37)**

Description: Surface Prep (Sandblast + Seal)

CS: Dural 335

DS:

Notes:

DD 3/22/16

DA 3/22/16

Large cracks

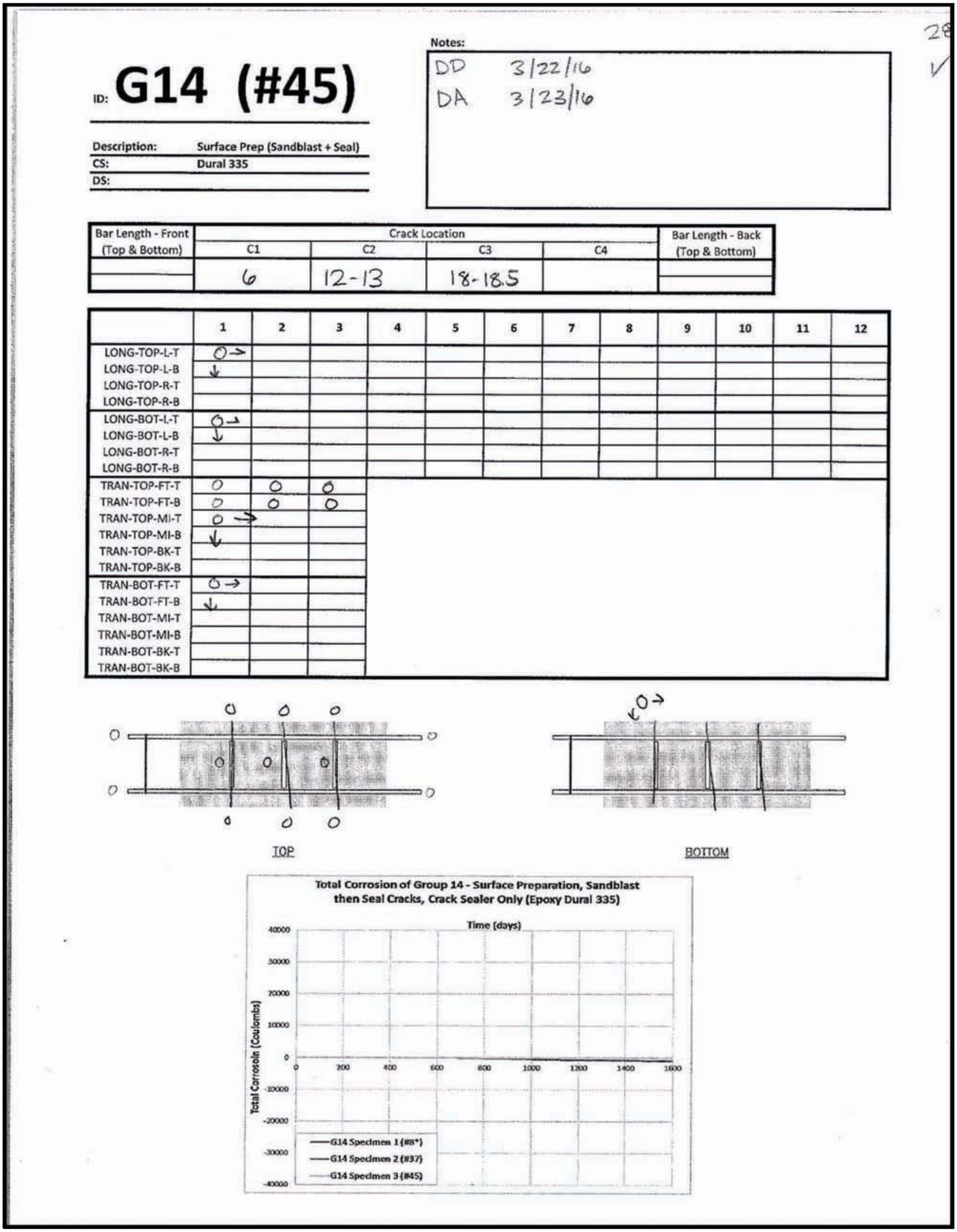
-Damaged by Chisel @ increment 3-4 of TR bar

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	6	10	13	19	
	0.035-0.05"		0.03-0.035	0.02"	

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 →											
LONG-TOP-L-B	E| | |	0 →										
LONG-TOP-R-T	0	0	8	4	0 →							
LONG-TOP-R-B	0	0	8	2	0 →							
LONG-BOT-L-T	0 →											
LONG-BOT-L-B	↓											
LONG-BOT-R-T												
LONG-BOT-R-B												
TRAN-TOP-FT-T	2	8	2									
TRAN-TOP-FT-B	2	4	2									
TRAN-TOP-MI-T	0	0	0									
TRAN-TOP-MI-B	0	0	0									
TRAN-TOP-BK-T	0	0	2									
TRAN-TOP-BK-B	0	0	1									
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Total Corrosion of Group 14 - Surface Preparation, Sandblast then Seal Cracks, Crack Sealer Only (Epoxy Dural 335)

Figure C.27 Autopsy notes for Specimen No. 37.



28 ✓

ID: **G14 (#45)**

Notes:

DD 3/22/16

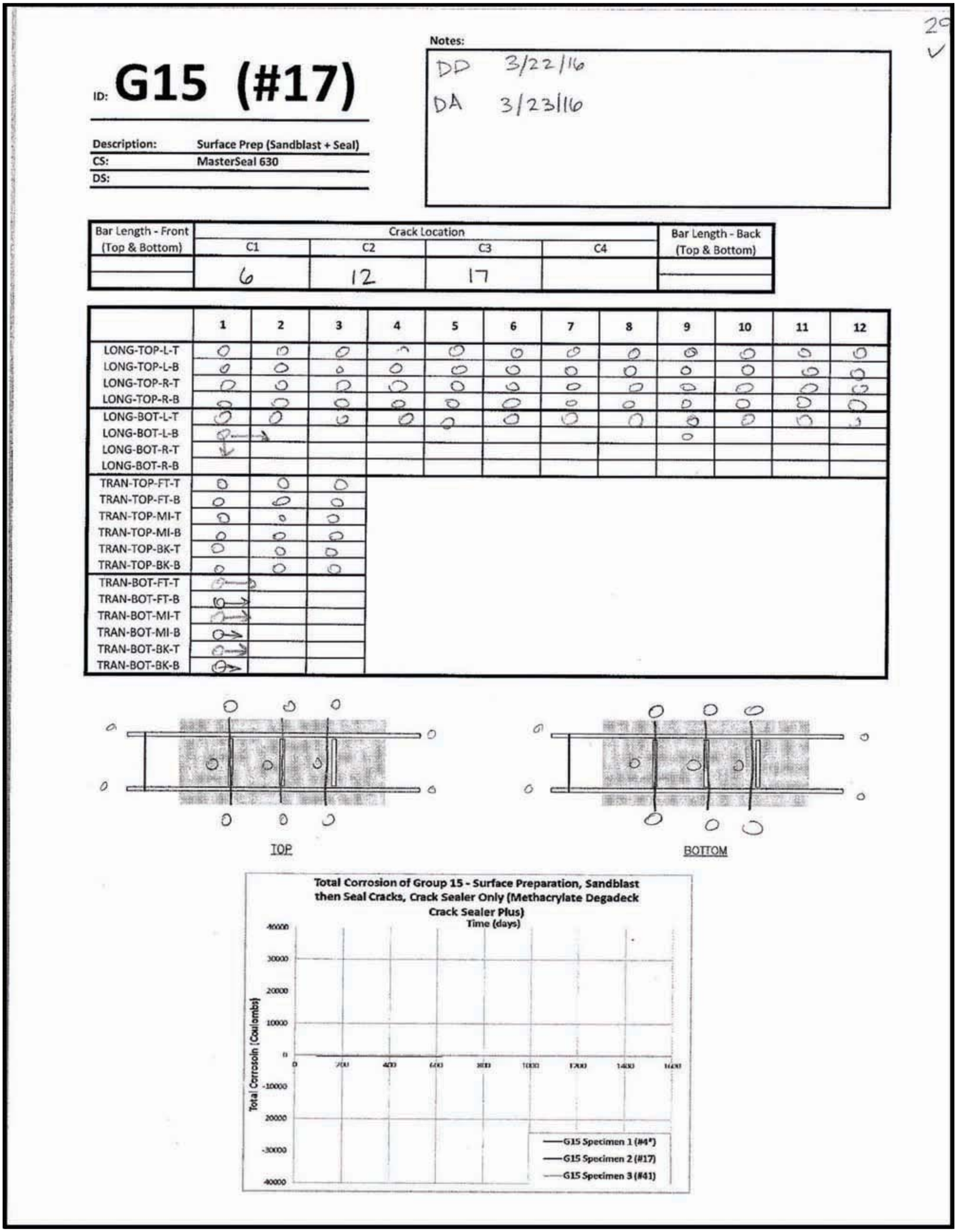
DA 3/23/16

Description:	Surface Prep (Sandblast + Seal)
CS:	Dural 335
DS:	

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	6	12-13	18-18.5		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	O→											
LONG-TOP-L-B	↓											
LONG-TOP-R-T												
LONG-TOP-R-B												
LONG-BOT-L-T	O→											
LONG-BOT-L-B	↓											
LONG-BOT-R-T												
LONG-BOT-R-B												
TRAN-TOP-FT-T	O	O	O									
TRAN-TOP-FT-B	O	O	O									
TRAN-TOP-MI-T	O →											
TRAN-TOP-MI-B	↓											
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	O →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.28 Autopsy notes for Specimen No. 45.



ID: **G15 (#17)**

Notes:
DD 3/22/16
DA 3/23/16

Description: Surface Prep (Sandblast + Seal)
CS: MasterSeal 630
DS:

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	6	12	17		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	○	○	○	○	○	○	○	○	○	○	○	○
LONG-TOP-L-B	○	○	○	○	○	○	○	○	○	○	○	○
LONG-TOP-R-T	○	○	○	○	○	○	○	○	○	○	○	○
LONG-TOP-R-B	○	○	○	○	○	○	○	○	○	○	○	○
LONG-BOT-L-T	○	○	○	○	○	○	○	○	○	○	○	○
LONG-BOT-L-B	○→								○			
LONG-BOT-R-T	↓											
LONG-BOT-R-B												
TRAN-TOP-FT-T	○	○	○									
TRAN-TOP-FT-B	○	○	○									
TRAN-TOP-MI-T	○	○	○									
TRAN-TOP-MI-B	○	○	○									
TRAN-TOP-BK-T	○	○	○									
TRAN-TOP-BK-B	○	○	○									
TRAN-BOT-FT-T	○→											
TRAN-BOT-FT-B	○→											
TRAN-BOT-MI-T	○→											
TRAN-BOT-MI-B	○→											
TRAN-BOT-BK-T	○→											
TRAN-BOT-BK-B	○→											

Figure C.29 Autopsy notes for Specimen No. 17.

30
✓

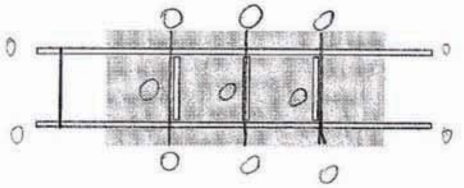
ID: **G15 (#41)**

Notes:
DD 3/23/16
DA 3/23/16

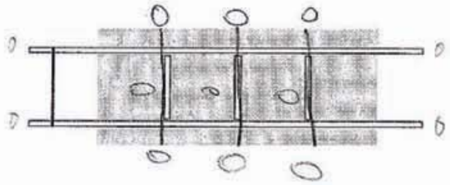
Description: Surface Prep (Sandblast + Seal)
CS: MasterSeal 630
DS:

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	5.5-6	12	18-18.5		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0	0	0	0	0	0	0	0	0	0	0	0
LONG-TOP-L-B	0→											
LONG-TOP-R-T	0→											
LONG-TOP-R-B	0→											
LONG-BOT-L-T	0→											
LONG-BOT-L-B	0→											
LONG-BOT-R-T	0	0→										
LONG-BOT-R-B	0	0	0	0	0	0→						
TRAN-TOP-FT-T	0→											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0	0	0									
TRAN-BOT-FT-B	0→											
TRAN-BOT-MI-T	0	0	0									
TRAN-BOT-MI-B	0→											
TRAN-BOT-BK-T	0	0	0									
TRAN-BOT-BK-B	0→											



TOP



BOTTOM

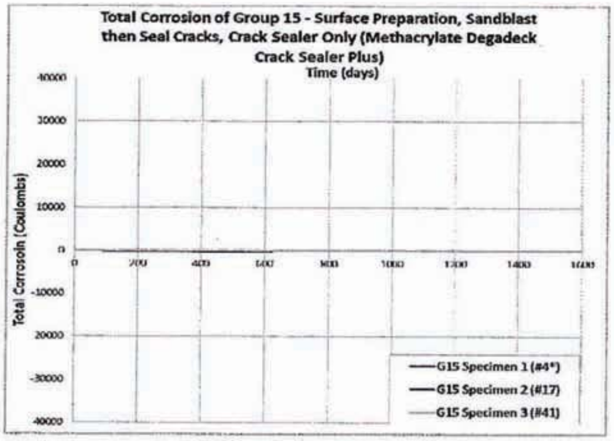
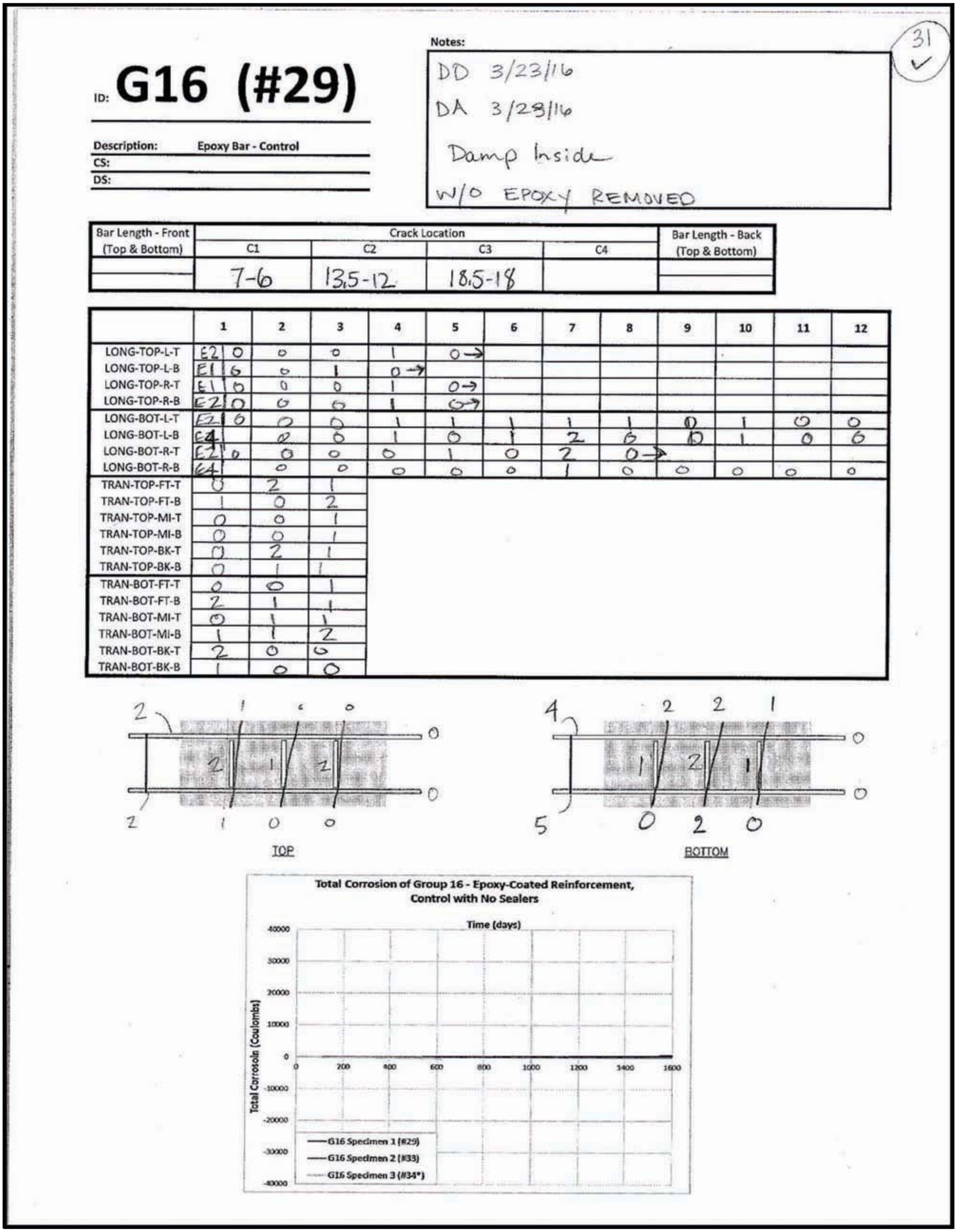


Figure C.30 Autopsy notes for Specimen No. 41.



31 ✓

ID: G16 (#29)

Description: Epoxy Bar - Control

CS:

DS:

Notes:

DD 3/23/16

DA 3/28/16

Damp Inside

W/O EPOXY REMOVED

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	7-6	13.5-12	18.5-18		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E2 0	0	0	1	0→							
LONG-TOP-L-B	E1 6	0	1	0→								
LONG-TOP-R-T	E1 0	0	0	1	0→							
LONG-TOP-R-B	E2 0	0	0	1	0→							
LONG-BOT-L-T	E2 6	0	0	1	1	1	1	1	0	1	0	0
LONG-BOT-L-B	E4	0	0	1	0	1	2	0	0	1	0	0
LONG-BOT-R-T	E2 0	0	0	0	1	0	2	0→				
LONG-BOT-R-B	E4	0	0	0	0	0	1	0	0	0	0	0
TRAN-TOP-FT-T	0	2	1									
TRAN-TOP-FT-B	1	0	2									
TRAN-TOP-MI-T	0	0	1									
TRAN-TOP-MI-B	0	0	1									
TRAN-TOP-BK-T	0	2	1									
TRAN-TOP-BK-B	0	1	1									
TRAN-BOT-FT-T	0	0	1									
TRAN-BOT-FT-B	2	1	1									
TRAN-BOT-MI-T	0	1	1									
TRAN-BOT-MI-B	1	1	2									
TRAN-BOT-BK-T	2	0	0									
TRAN-BOT-BK-B	1	0	0									

Figure C.31 Autopsy notes for Specimen No. 29.

32 ✓

ID: **G16 (#33)**

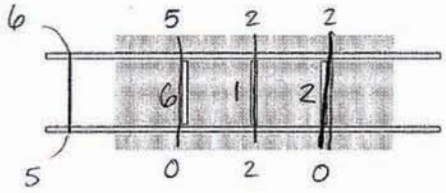
Description: Epoxy Bar - Control
CS:
DS:

Notes:

DD 3/23/16
DA 3/23/16
Resistor was loose
Damp Inside
W/O EPOXY REMOVED

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	5.5	12	18.5-18		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E4 0	0	0	1	0	0	1	0	0	0	0	0
LONG-TOP-L-B	E4 0	0	0	2	0	1	2	0	0	1	0	0
LONG-TOP-R-T	E4 0	0	0	0	0	0	1	0	0	0	0	0
LONG-TOP-R-B	E4 0	0	0	0	0	0	1	0	0	0	0	0
LONG-BOT-L-T	E1 0	0	0	1	0	0	0	0	0	0	0	0 E1
LONG-BOT-L-B	E1 0	0	0	1	0	0	0	0	0	•	0	0 E1
LONG-BOT-R-T	E4 0	0	0	1	0	0	2	0 →				
LONG-BOT-R-B	E4 0	0	0	1	0	0	2	0 →				
TRAN-TOP-FT-T	4	4	0									
TRAN-TOP-FT-B	4	4	0									
TRAN-TOP-MI-T	0	0	1									
TRAN-TOP-MI-B	1	0	1									
TRAN-TOP-BK-T	0	0	2									
TRAN-TOP-BK-B	0	0	2									
TRAN-BOT-FT-T	0	0	0									
TRAN-BOT-FT-B	1	1	1									
TRAN-BOT-MI-T	0	0	0									
TRAN-BOT-MI-B	1	0	1									
TRAN-BOT-BK-T	1	0	0									
TRAN-BOT-BK-B	1	0	0									



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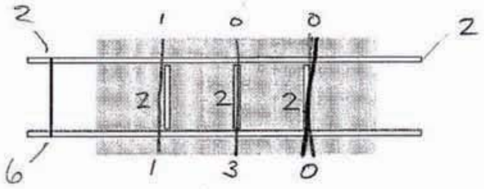


BOTTOM

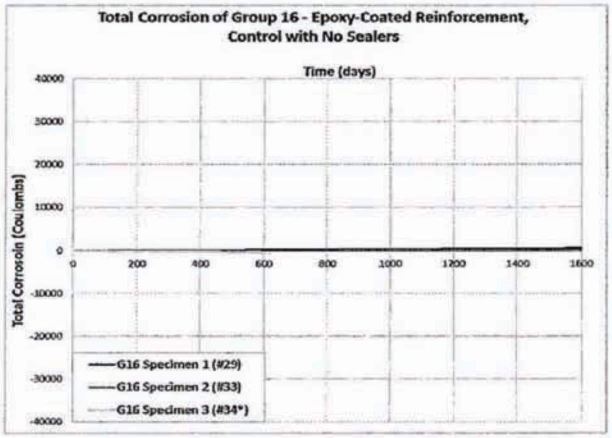
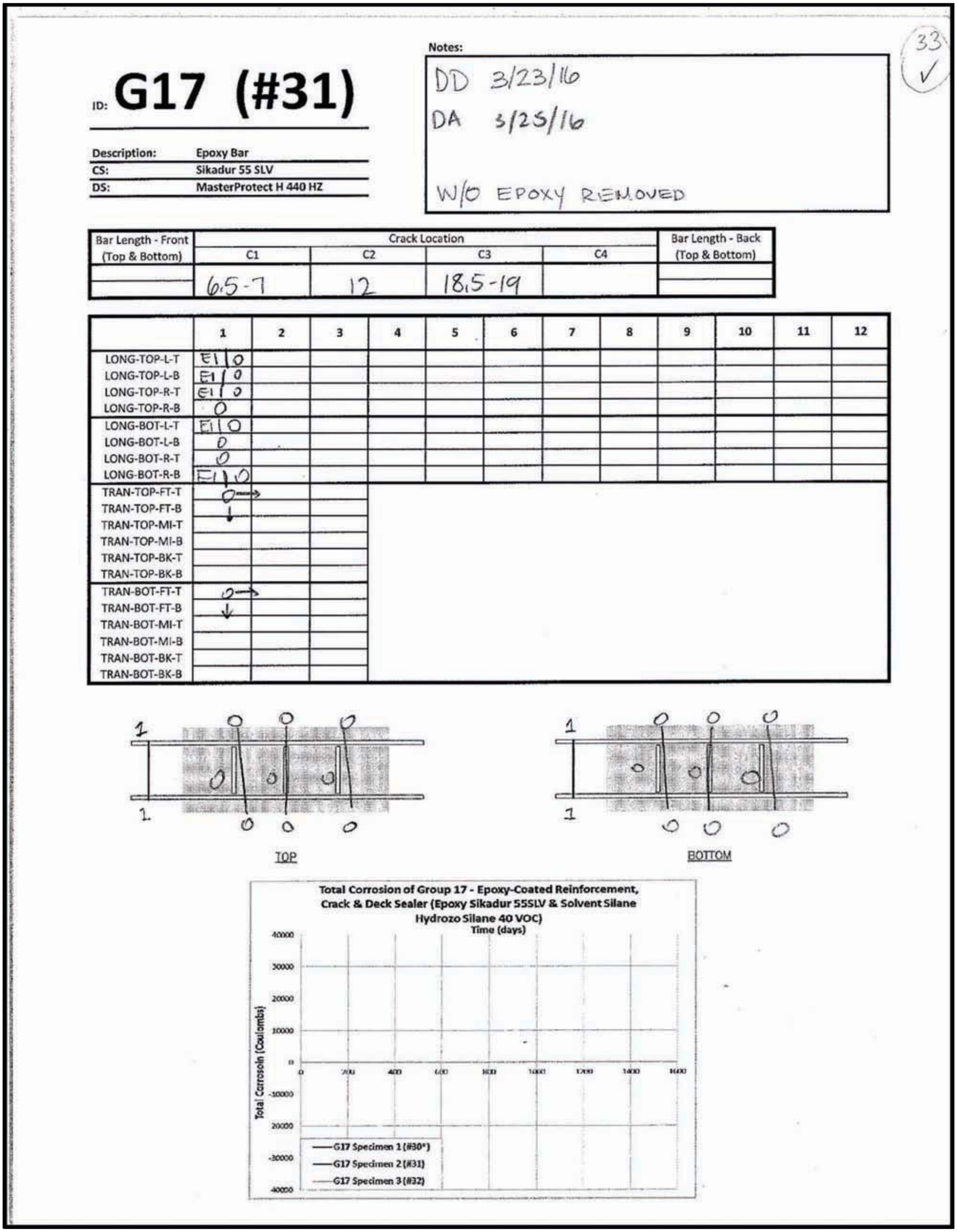


Figure C.32 Autopsy notes for Specimen No. 33.



33
✓

ID: **G17 (#31)**

Description:	Epoxy Bar
CS:	Sikadur 55 SLV
DS:	MasterProtect H 440 HZ

Notes:

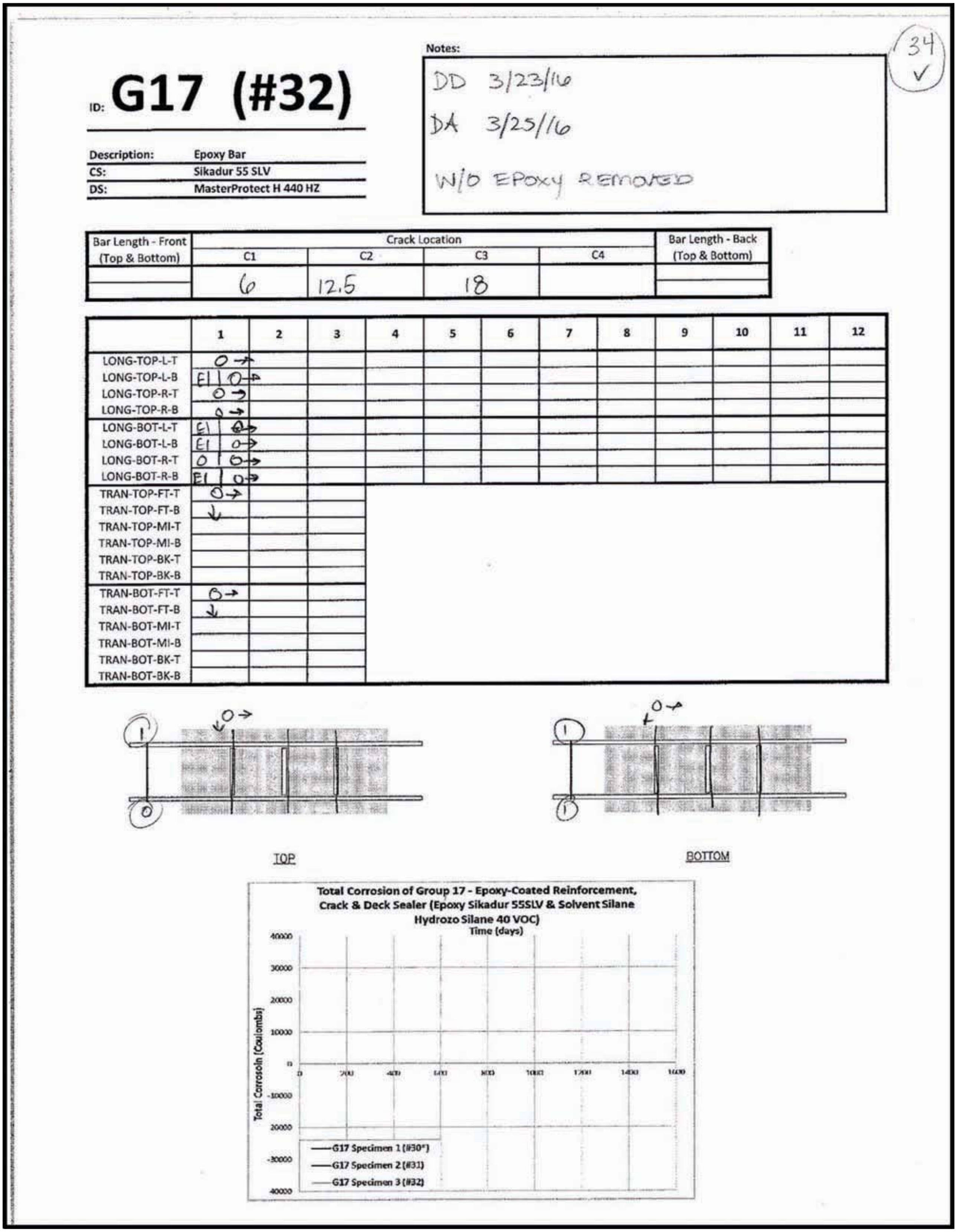
DD 3/23/16
DA 3/25/16

W/O EPOXY REMOVED

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	6.5-7	12	18.5-19		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 | 0											
LONG-TOP-L-B	E1 / 0											
LONG-TOP-R-T	E1 / 0											
LONG-TOP-R-B	0											
LONG-BOT-L-T	E1 | 0											
LONG-BOT-L-B	0											
LONG-BOT-R-T	0											
LONG-BOT-R-B	E1 | 0											
TRAN-TOP-FT-T	0 →											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.33 Autopsy notes for Specimen No. 31.



ID: **G17 (#32)**

34 ✓

Description:	Epoxy Bar
CS:	Sikadur 55 SLV
DS:	MasterProtect H 440 HZ

Notes:

DD 3/23/16

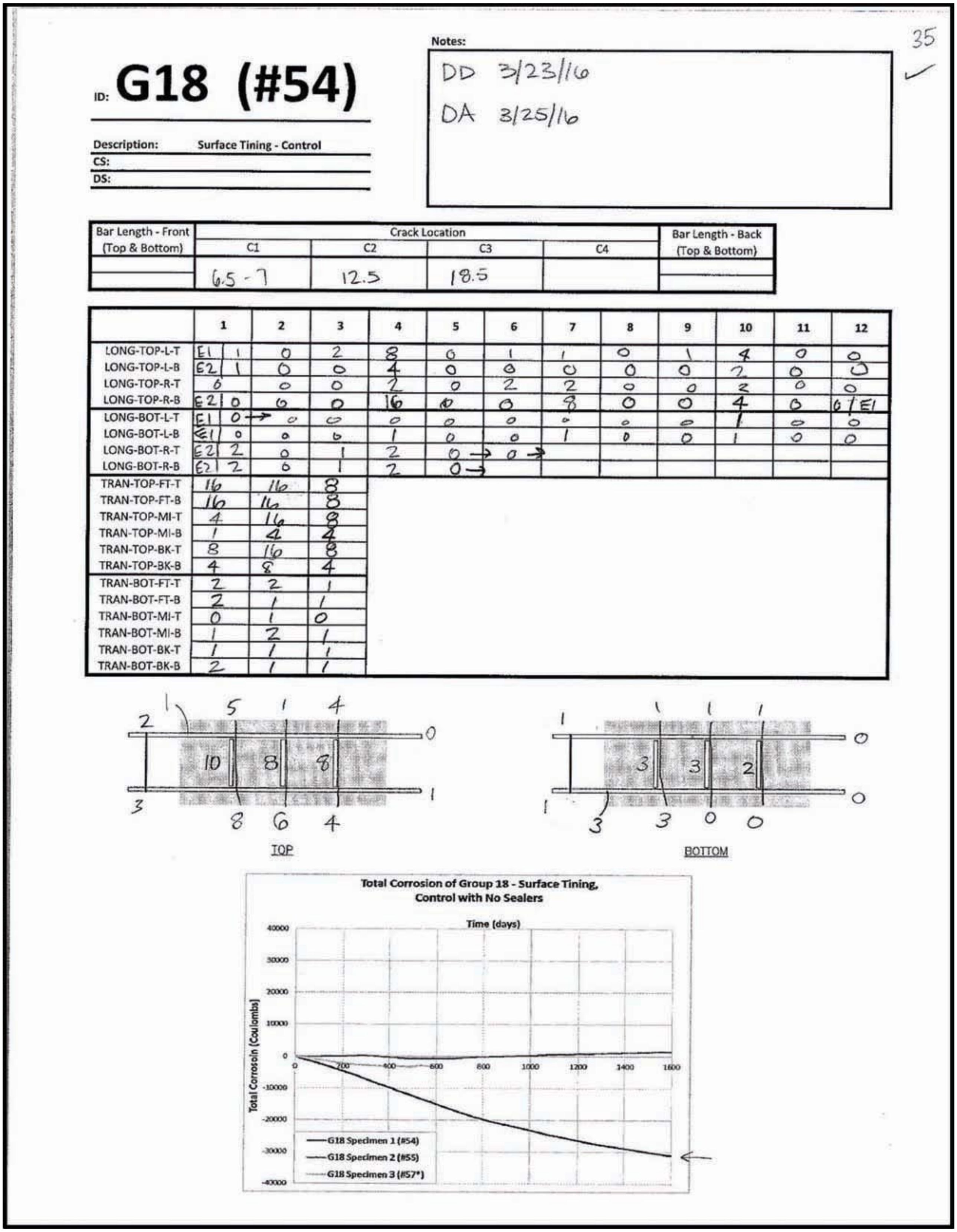
DA 3/25/16

W/O EPOXY REMOVED

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	6	12.5	18		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	O →											
LONG-TOP-L-B	E1 | O →											
LONG-TOP-R-T	O →											
LONG-TOP-R-B	O →											
LONG-BOT-L-T	E1 | O →											
LONG-BOT-L-B	E1 | O →											
LONG-BOT-R-T	O | O →											
LONG-BOT-R-B	E1 | O →											
TRAN-TOP-FT-T	O →											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	O →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.34 Autopsy notes for Specimen No. 32.



35 ✓

ID: **G18 (#54)**

Description: Surface Tining - Control
CS:
DS:

Notes:
DD 3/23/16
DA 3/25/16

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	6.5 - 7	12.5	18.5		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 1	0	2	8	0	1	1	0	1	4	0	0
LONG-TOP-L-B	E2 1	0	0	4	0	0	0	0	0	2	0	0
LONG-TOP-R-T	0	0	0	2	0	2	2	0	0	2	0	0
LONG-TOP-R-B	E2 0	0	0	16	0	0	8	0	0	4	0	0 / E1
LONG-BOT-L-T	E1 0 →	0	0	0	0	0	0	0	0	1	0	0
LONG-BOT-L-B	E1 0	0	0	1	0	0	1	0	0	1	0	0
LONG-BOT-R-T	E2 2	0	1	2	0 →	0 →						
LONG-BOT-R-B	E2 2	0	1	2	0 →							
TRAN-TOP-FT-T	16	16	8									
TRAN-TOP-FT-B	16	16	8									
TRAN-TOP-MI-T	4	16	8									
TRAN-TOP-MI-B	1	4	4									
TRAN-TOP-BK-T	8	16	8									
TRAN-TOP-BK-B	4	8	4									
TRAN-BOT-FT-T	2	2	1									
TRAN-BOT-FT-B	2	1	1									
TRAN-BOT-MI-T	0	1	0									
TRAN-BOT-MI-B	1	2	1									
TRAN-BOT-BK-T	1	1	1									
TRAN-BOT-BK-B	2	1	1									

Total Corrosion of Group 18 - Surface Tining, Control with No Sealers

Figure C.35 Autopsy notes for Specimen No. 54.

36
✓

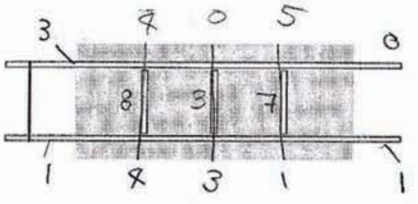
ID: G18 (#55)

Notes:
DD 3/23/16
DA 4/2/16

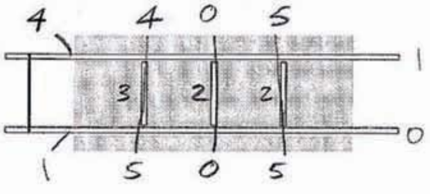
Description: Surface Tining - Control
CS:
DS:

Bar Length - Front (Top & Bottom)	Crack Location C1	C2	C3	C4	Bar Length - Back (Top & Bottom)
	6-5.5	12	17.5-18		

	1		2	3	4	5	6	7	8	9	10	11	12	
LONG-TOP-L-T	E2	0	0	0	4	0	0	0	0	2	0	0	0	0
LONG-TOP-L-B	E2	0	0	2	2	0	0	0	0	0	8	0	0	0
LONG-TOP-R-T	0	0	0	0	8	0	0	4	0		2	0	0	0
LONG-TOP-R-B	E1	0	0	2	4	0	0	2	0	0	0	0	0	E1
LONG-BOT-L-T	E2	2	0	0	2	0	0	0	0	0	4	2	0	E1
LONG-BOT-L-B	E2	2	6	0	4	0	0	0	0	0	2	0	0	0
LONG-BOT-R-T	0	0	0	4	4	0	0	6	0	2	8	0	0	0
LONG-BOT-R-B	E1		0	0	2	0	0	0	0	1	1	0	0	0
TRAN-TOP-FT-T	1		1	1										
TRAN-TOP-FT-B	16		8	16										
TRAN-TOP-MI-T	1		2	1										
TRAN-TOP-MI-B	1		2	1										
TRAN-TOP-BK-T	4		4	4										
TRAN-TOP-BK-B	8		8	8										
TRAN-BOT-FT-T	2		0	2										
TRAN-BOT-FT-B	4		0	2										
TRAN-BOT-MI-T	1		1	1										
TRAN-BOT-MI-B	0		0	0										
TRAN-BOT-BK-T	0		0	0										
TRAN-BOT-BK-B	2		0	1										



TOP



BOTTOM

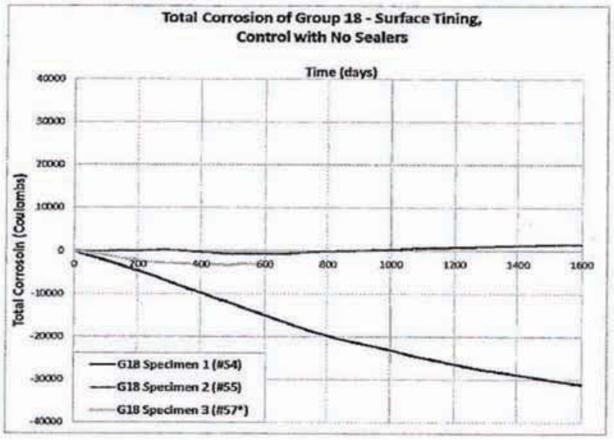
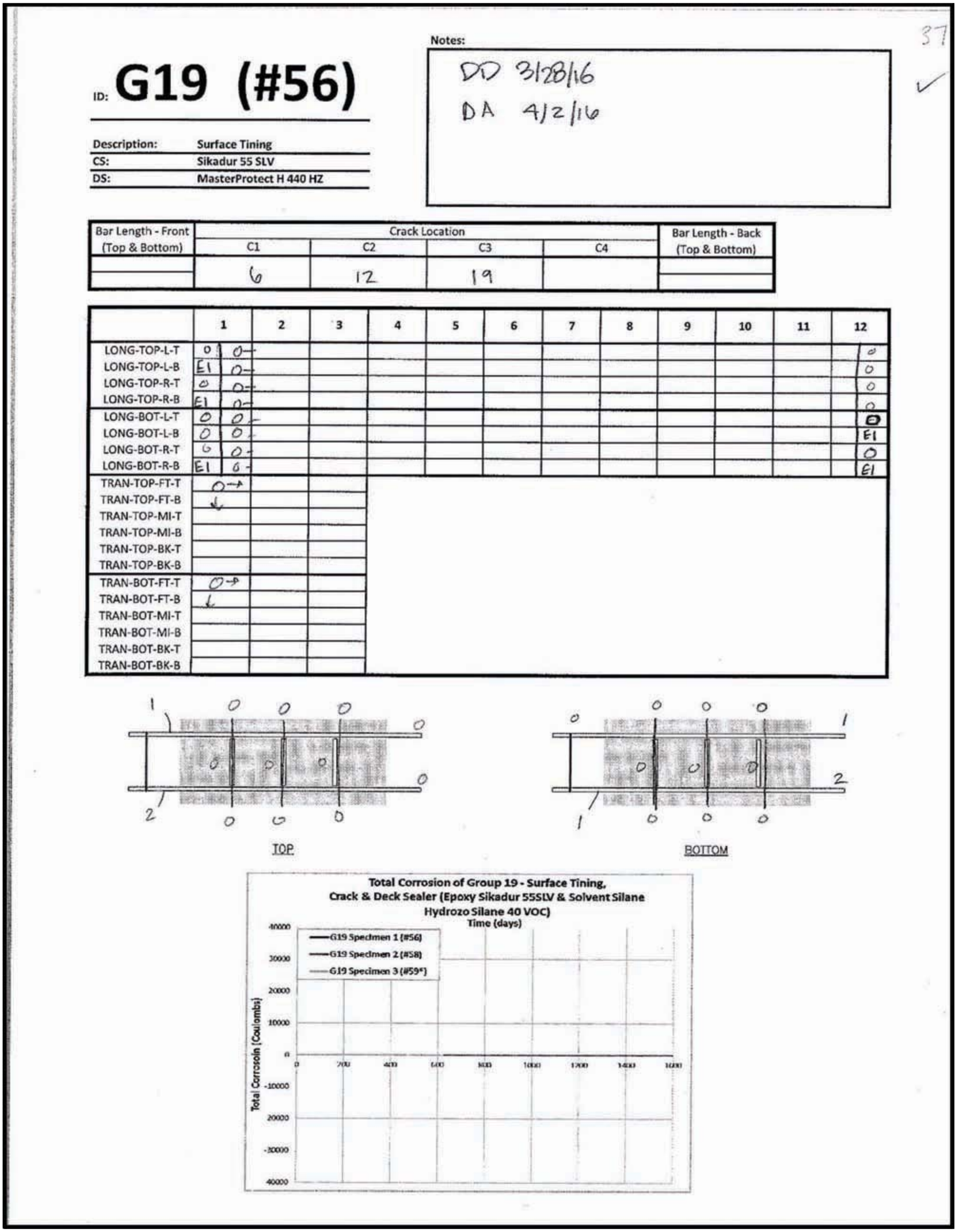


Figure C.36 Autopsy notes for Specimen No. 55.



37

✓

ID: **G19 (#56)**

Notes:

DD 3/28/16

DA 4/2/16

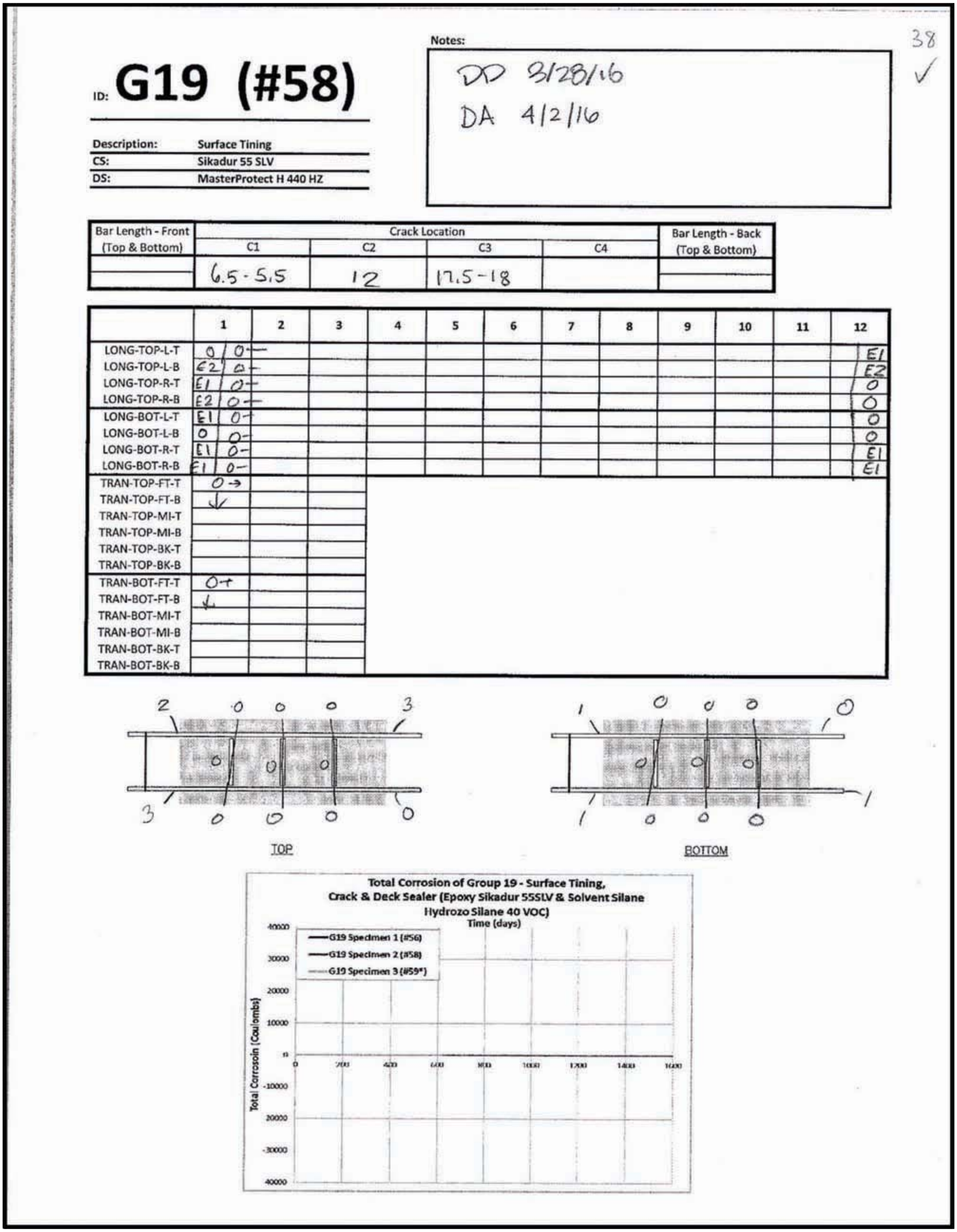
Description:	Surface Tining
CS:	Sikadur 55 SLV
DS:	MasterProtect H 440 HZ

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	6	12	19		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 | 0—											0
LONG-TOP-L-B	E1 | 0—											0
LONG-TOP-R-T	0 | 0—											0
LONG-TOP-R-B	E1 | 0—											0
LONG-BOT-L-T	0 | 0—											0
LONG-BOT-L-B	0 | 0—											E1
LONG-BOT-R-T	6 | 0—											0
LONG-BOT-R-B	E1 | 6—											E1
TRAN-TOP-FT-T	0 →											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Total Corrosion of Group 19 - Surface Tining, Crack & Deck Sealer (Epoxy Sikadur 55SLV & Solvent Silane Hydrozo Silane 40 VOC)

Figure C.37 Autopsy notes for Specimen No. 56.



38 ✓

ID: **G19 (#58)**

Description:	Surface Tining
CS:	Sikadur 55 SLV
DS:	MasterProtect H 440 HZ

Notes:

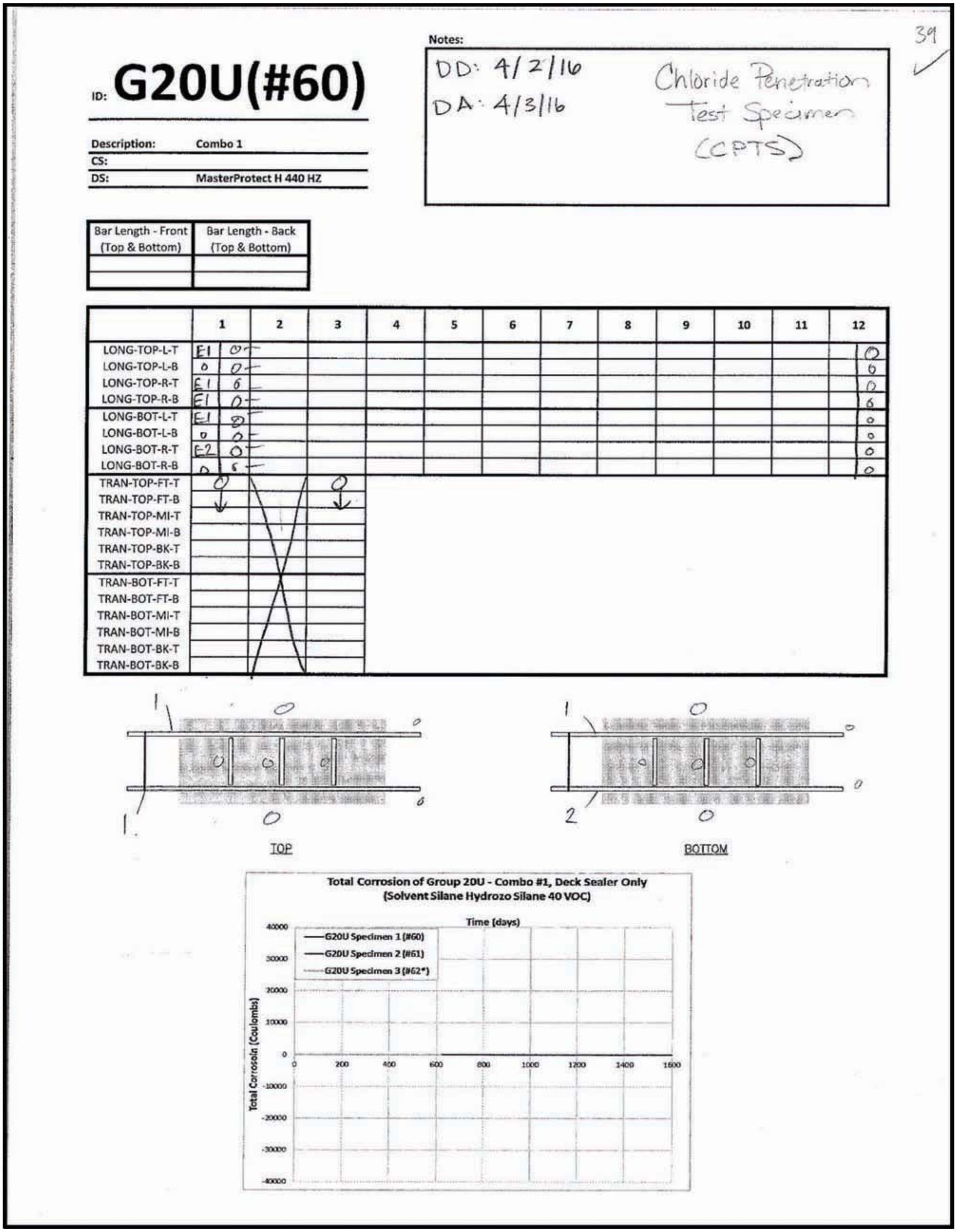
DD 3/28/16
DA 4/2/16

Bar Length - Front (Top & Bottom)	Crack Location				Bar Length - Back (Top & Bottom)
	C1	C2	C3	C4	
	6.5-5.5	12	17.5-18		

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 / 0—	—										E1
LONG-TOP-L-B	E2 / 0—											E2
LONG-TOP-R-T	E1 / 0—											0
LONG-TOP-R-B	E2 / 0—											0
LONG-BOT-L-T	E1 / 0—											0
LONG-BOT-L-B	0 / 0—											0
LONG-BOT-R-T	E1 / 0—											E1
LONG-BOT-R-B	E1 / 0—											E1
TRAN-TOP-FT-T	0 →											
TRAN-TOP-FT-B	↓											
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T	0 →											
TRAN-BOT-FT-B	↓											
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Total Corrosion of Group 19 - Surface Tining, Crack & Deck Sealer (Epoxy Sikadur 55SLV & Solvent Silane Hydrozo Silane 40 VOC)

Figure C.38 Autopsy notes for Specimen No. 58.



39 ✓

ID: **G20U(#60)**

Description: Combo 1
CS:
DS: MasterProtect H 440 HZ

Notes:
DD: 4/2/16
DA: 4/3/16
Chloride Penetration Test Specimen (CPTS)

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 0											0
LONG-TOP-L-B	0 0											6
LONG-TOP-R-T	E1 6											0
LONG-TOP-R-B	E1 0											6
LONG-BOT-L-T	E1 0											0
LONG-BOT-L-B	0 0											0
LONG-BOT-R-T	E2 0											0
LONG-BOT-R-B	0 6											0
TRAN-TOP-FT-T	0		0									
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.39 Autopsy notes for Specimen No. 60.

40
✓

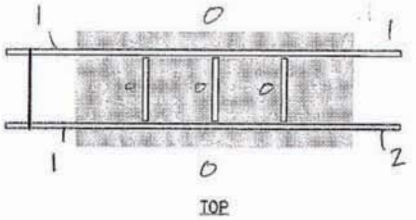
ID: **G20U(#61)**

Notes:
DD 4/2/16
DA 4/3/16

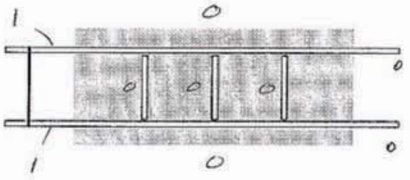
Description: Combo 1
CS:
DS: MasterProtect H 440 HZ

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 0											0 E1
LONG-TOP-L-B	E1 0											0 E1
LONG-TOP-R-T	0 0											0 E1
LONG-TOP-R-B	E1 0											0 E2
LONG-BOT-L-T	E1 0											0 0
LONG-BOT-L-B	E1 0											0 0
LONG-BOT-R-T	E1 0											0 0
LONG-BOT-R-B	0 0											0 0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												



TOP



BOTTOM

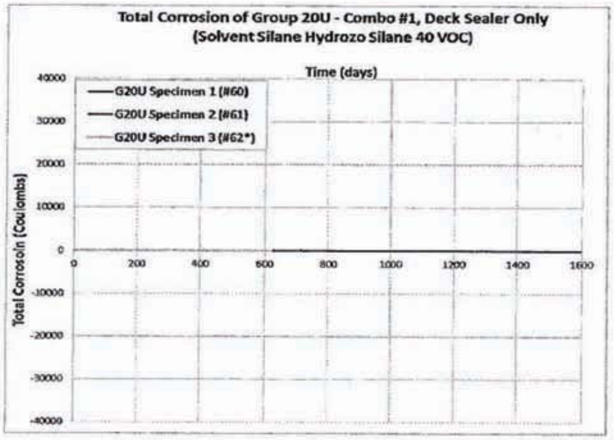
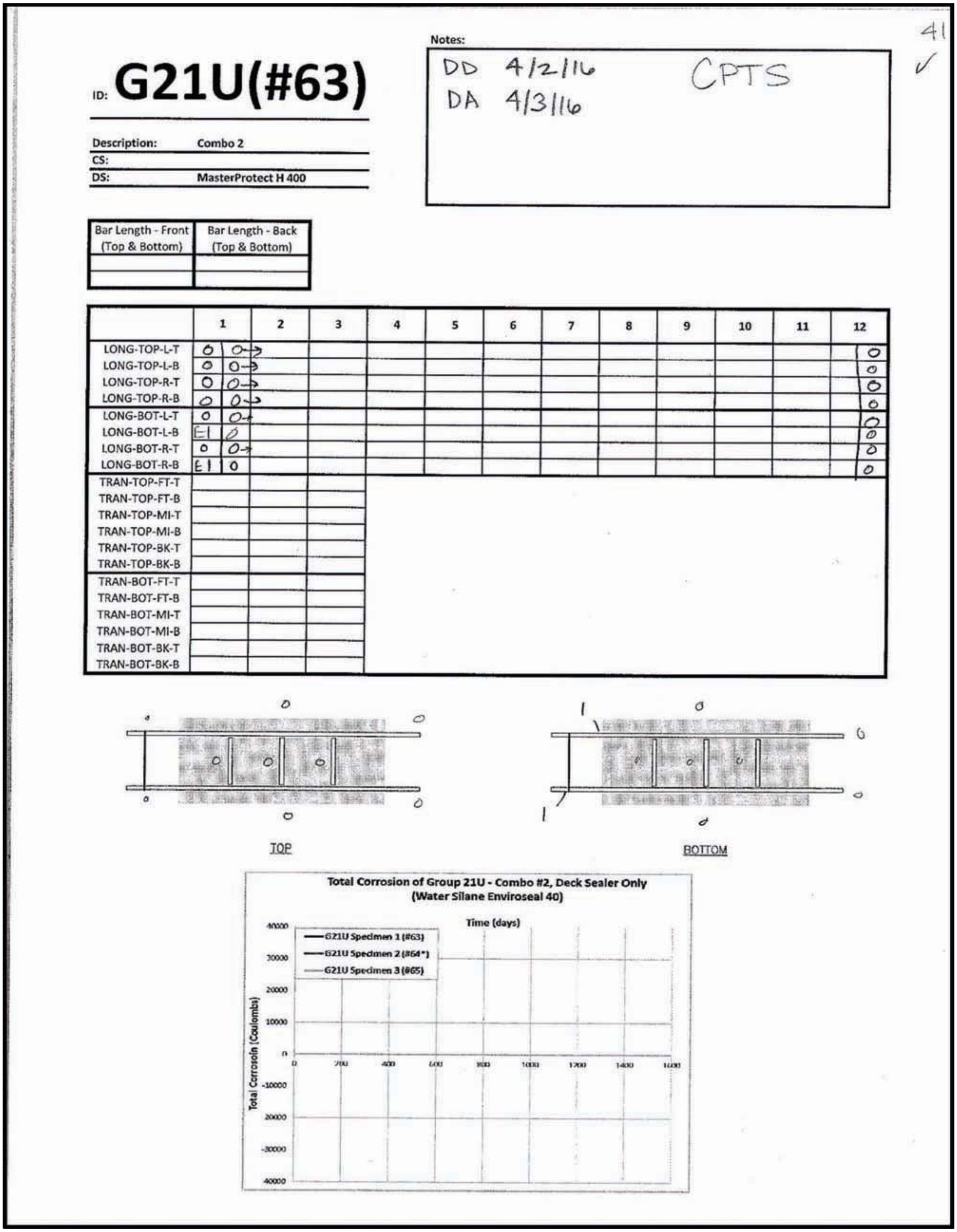


Figure C.40 Autopsy notes for Specimen No. 61.



41 ✓

ID: **G21U(#63)**

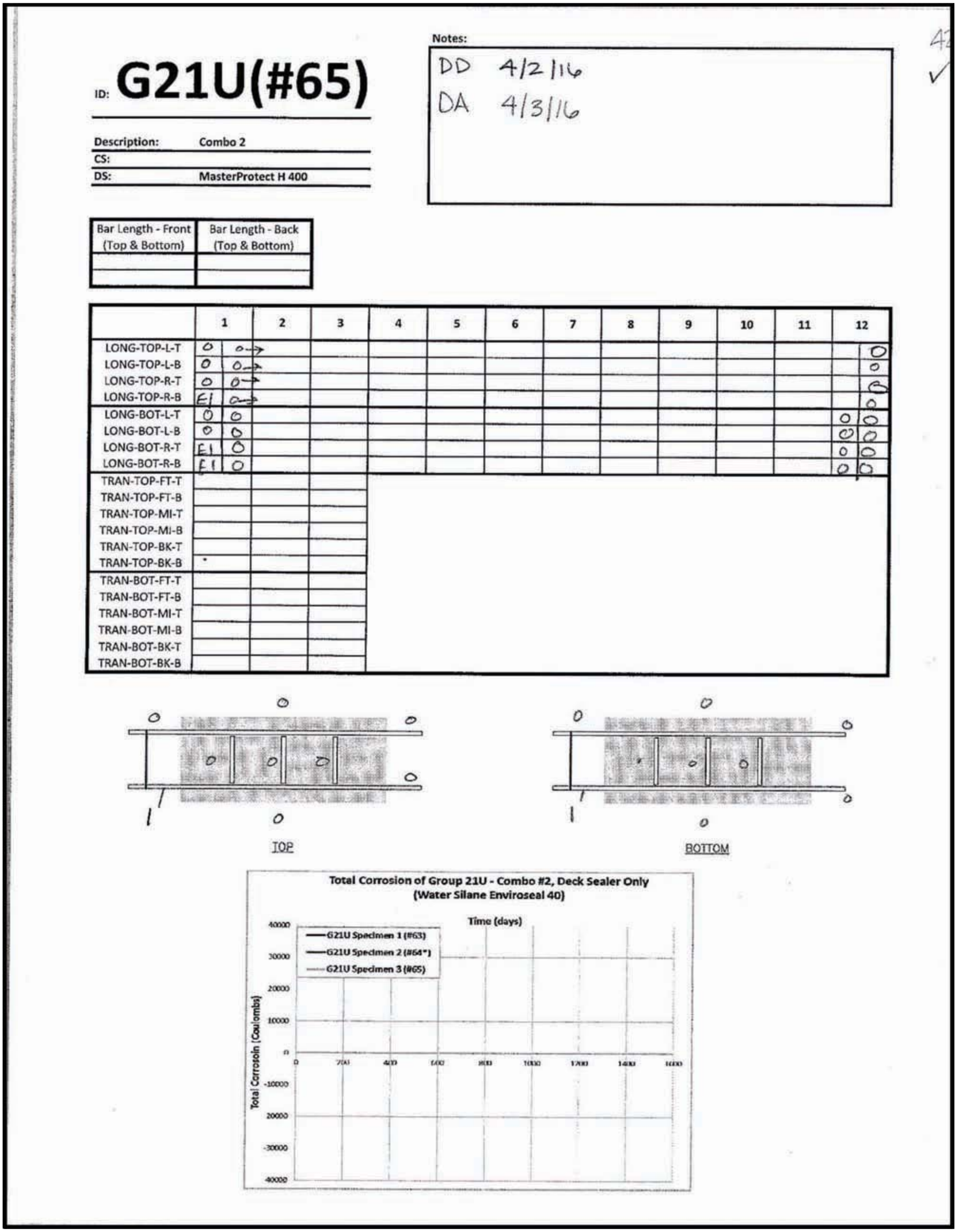
Description: Combo 2
CS:
DS: MasterProtect H 400

Notes:
DD 4/2/16 CPTS
DA 4/3/16

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0	0→										0
LONG-TOP-L-B	0	0→										0
LONG-TOP-R-T	0	0→										0
LONG-TOP-R-B	0	0→										0
LONG-BOT-L-T	0	0→										0
LONG-BOT-L-B	E1	0										0
LONG-BOT-R-T	0	0→										0
LONG-BOT-R-B	E1	0										0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.41 Autopsy notes for Specimen No. 63.



ID: **G21U(#65)**

Notes:

DD 4/2/16
DA 4/3/16

4
✓

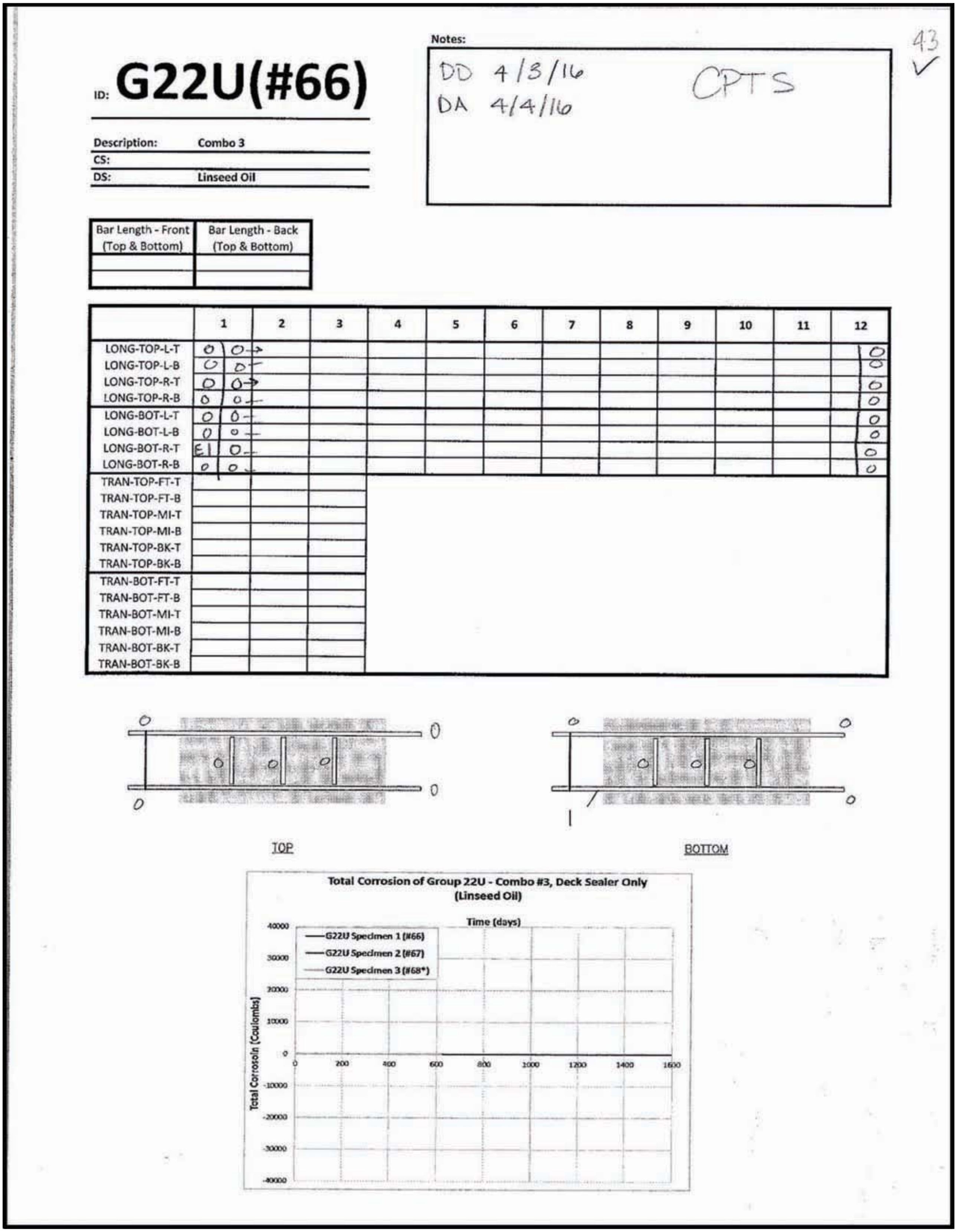
Description: Combo 2
CS:
DS: MasterProtect H 400

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0→											0
LONG-TOP-L-B	0 0→											0
LONG-TOP-R-T	0 0→											0
LONG-TOP-R-B	E1 0→											0
LONG-BOT-L-T	0 0											0 0
LONG-BOT-L-B	0 0											0 0
LONG-BOT-R-T	E1 0											0 0
LONG-BOT-R-B	E1 0											0 0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Total Corrosion of Group 21U - Combo #2, Deck Sealer Only
(Water Silane Enviroseal 40)

Figure C.42 Autopsy notes for Specimen No. 65.



43 ✓

ID: **G22U(#66)**

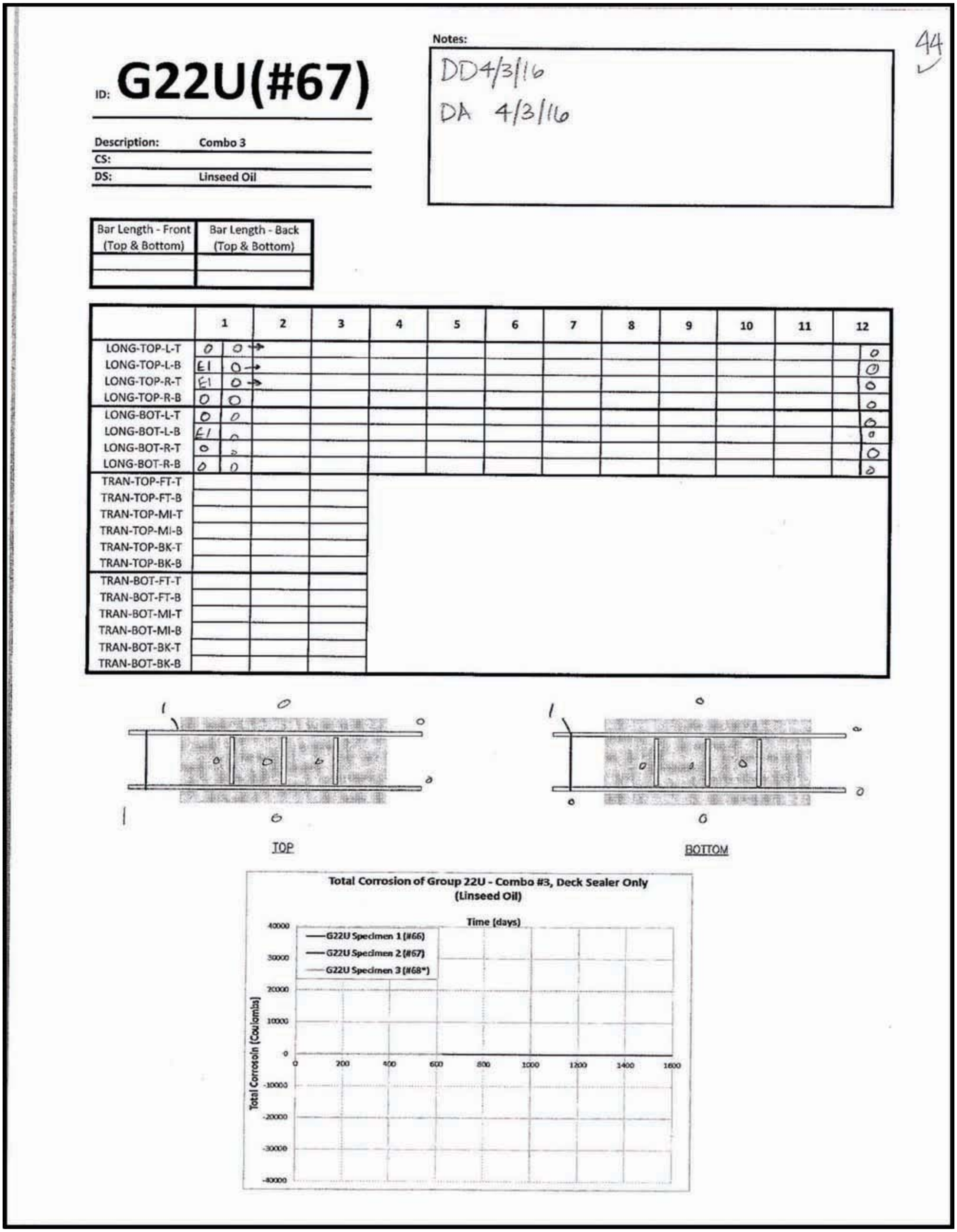
Description: Combo 3
CS:
DS: Linseed Oil

Notes:
DD 4/3/16 CPTS
DA 4/4/16

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 | 0	→										0
LONG-TOP-L-B	0 | 0	-										0
LONG-TOP-R-T	0 | 0	→										0
LONG-TOP-R-B	0 | 0	-										0
LONG-BOT-L-T	0 | 0	-										0
LONG-BOT-L-B	0 | 0	-										0
LONG-BOT-R-T	E1 | 0	-										0
LONG-BOT-R-B	0 | 0	-										0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.43 Autopsy notes for Specimen No. 66.



44 ✓

ID: **G22U(#67)**

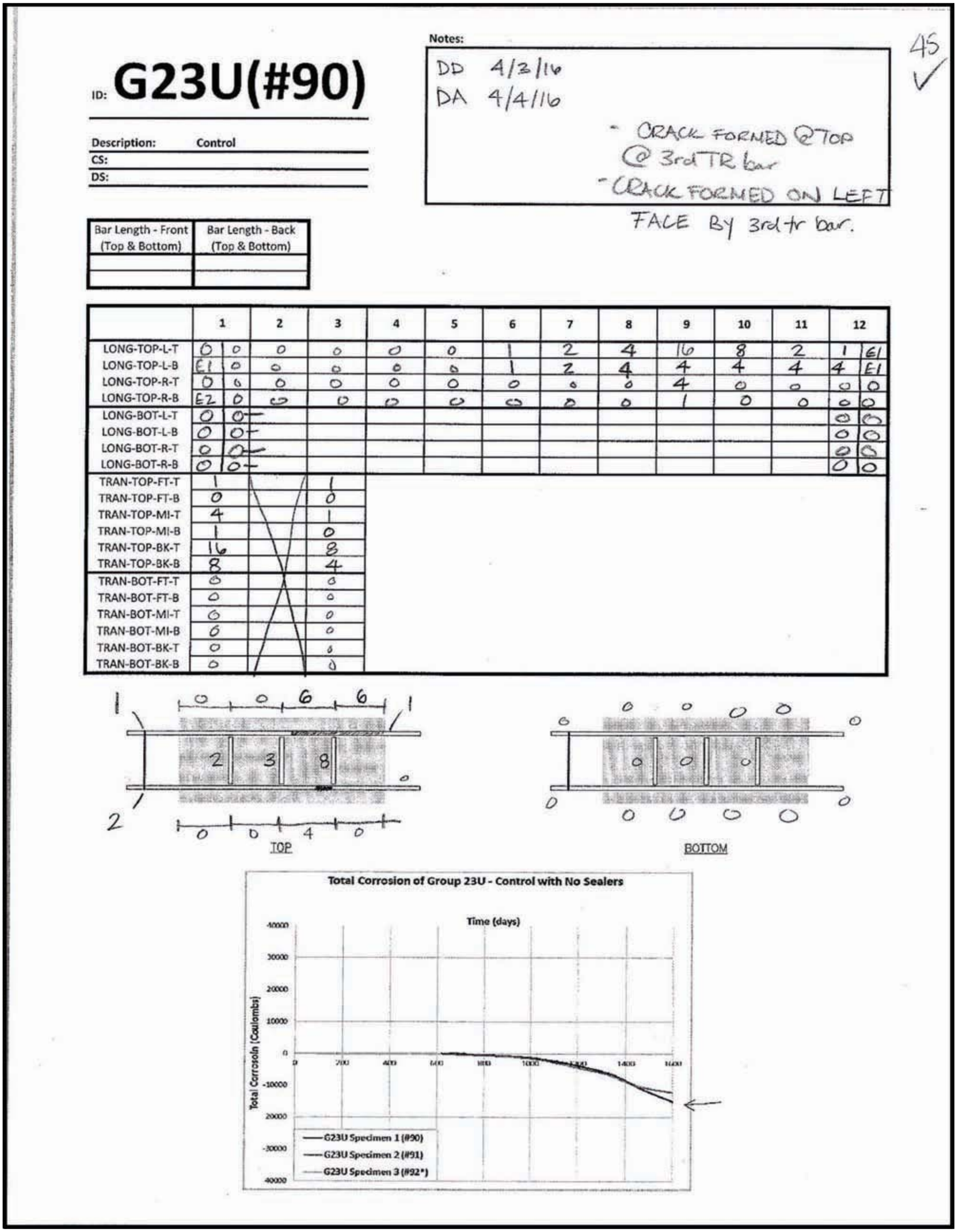
Notes:
DD4/3/16
DA 4/3/16

Description:	Combo 3
CS:	
DS:	Linseed Oil

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0 →											0
LONG-TOP-L-B	E1 0 →											0
LONG-TOP-R-T	E1 0 →											0
LONG-TOP-R-B	0 0											0
LONG-BOT-L-T	0 0											0
LONG-BOT-L-B	E1 0											0
LONG-BOT-R-T	0 0											0
LONG-BOT-R-B	0 0											0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.44 Autopsy notes for Specimen No. 67.



ID: **G23U(#90)**

45 ✓

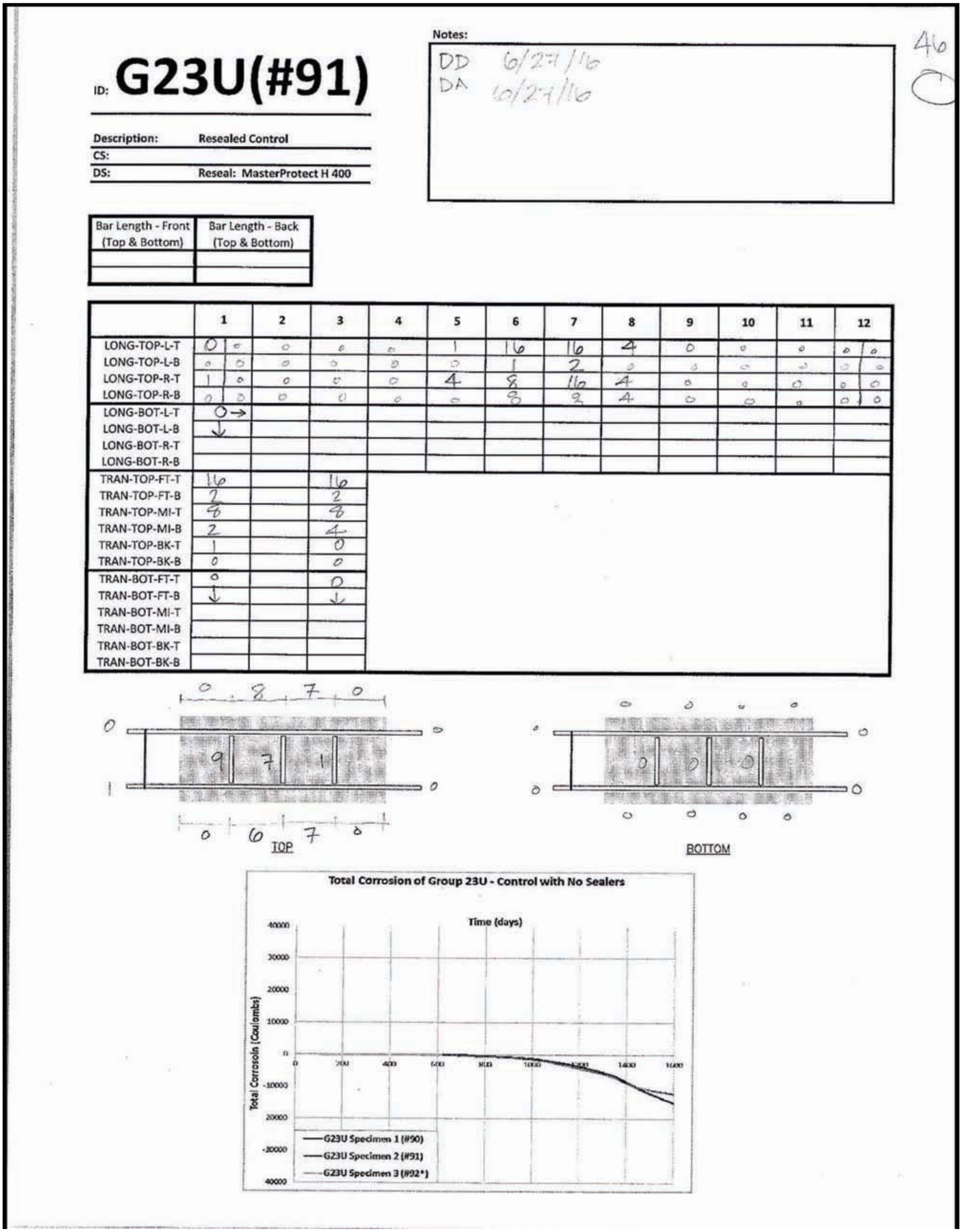
Description: Control
CS:
DS:

Notes:
DD 4/3/16
DA 4/4/16
- CRACK FORMED @ TOP @ 3rd TR bar
- CRACK FORMED ON LEFT FACE BY 3rd tr bar.

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1		2	3	4	5	6	7	8	9	10	11	12	
LONG-TOP-L-T	0	0	0	0	0	0	1	2	4	16	8	2	1	E1
LONG-TOP-L-B	E1	0	0	0	0	0	1	2	4	4	4	4	4	E1
LONG-TOP-R-T	0	0	0	0	0	0	0	0	0	4	0	0	0	0
LONG-TOP-R-B	E2	0	0	0	0	0	0	0	0	1	0	0	0	0
LONG-BOT-L-T	0	0											0	0
LONG-BOT-L-B	0	0											0	0
LONG-BOT-R-T	0	0											0	0
LONG-BOT-R-B	0	0											0	0
TRAN-TOP-FT-T	1			1										
TRAN-TOP-FT-B	0			0										
TRAN-TOP-MI-T	4			1										
TRAN-TOP-MI-B	1			0										
TRAN-TOP-BK-T	16			8										
TRAN-TOP-BK-B	8			4										
TRAN-BOT-FT-T	0			0										
TRAN-BOT-FT-B	0			0										
TRAN-BOT-MI-T	6			0										
TRAN-BOT-MI-B	6			0										
TRAN-BOT-BK-T	0			0										
TRAN-BOT-BK-B	0			0										

Figure C.45 Autopsy notes for Specimen No. 90.



46

Notes:

DD 6/27/16
DA 6/27/16

ID: **G23U(#91)**

Description:	**Resealed Control**
CS:	
DS:	**Reseal: MasterProtect H 400**

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0	0	0	0	1	16	16	4	0	0	0	0 0
LONG-TOP-L-B	0 0	0	0	0	0	1	2	0	0	0	0	0 0
LONG-TOP-R-T	1 0	0	0	0	4	8	16	4	0	0	0	0 0
LONG-TOP-R-B	0 0	0	0	0	0	8	8	4	0	0	0	0 0
LONG-BOT-L-T	0 →											
LONG-BOT-L-B	↓											
LONG-BOT-R-T												
LONG-BOT-R-B												
TRAN-TOP-FT-T	16		16									
TRAN-TOP-FT-B	2		2									
TRAN-TOP-MI-T	8		8									
TRAN-TOP-MI-B	2		4									
TRAN-TOP-BK-T	1		0									
TRAN-TOP-BK-B	0		0									
TRAN-BOT-FT-T	0		0									
TRAN-BOT-FT-B	↓		↓									
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.46 Autopsy notes for Specimen No. 91.

47
✓

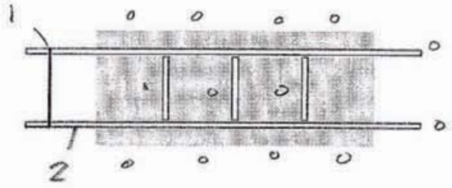
ID: G24U(#72)

Description: Sandblast + Seal
CS:
DS: MasterProtect H 440 HZ

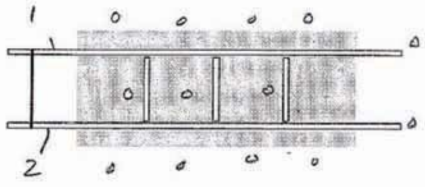
Notes:
DD 4/3/16 DRILLED ✓
DA 4/5/16 Chloride Penetration Test Specimen

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0											0 0
LONG-TOP-L-B	E1 0											0 0
LONG-TOP-R-T	E2 0											0 0
LONG-TOP-R-B	E1 0											0 0
LONG-BOT-L-T	E1 0											0 0
LONG-BOT-L-B	E1 0											0 0
LONG-BOT-R-T	E1 0											0 0
LONG-BOT-R-B	E2 0											0 0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												



TOP



BOTTOM

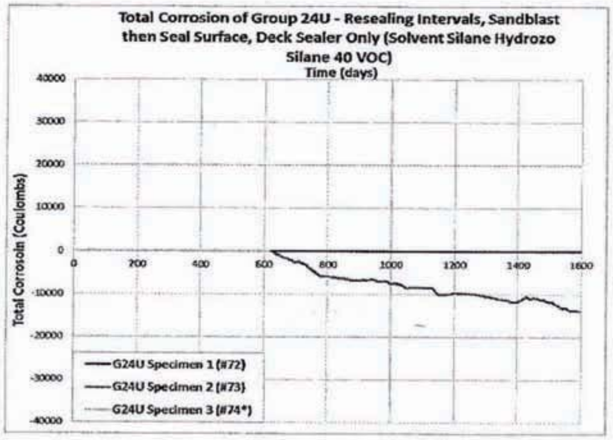
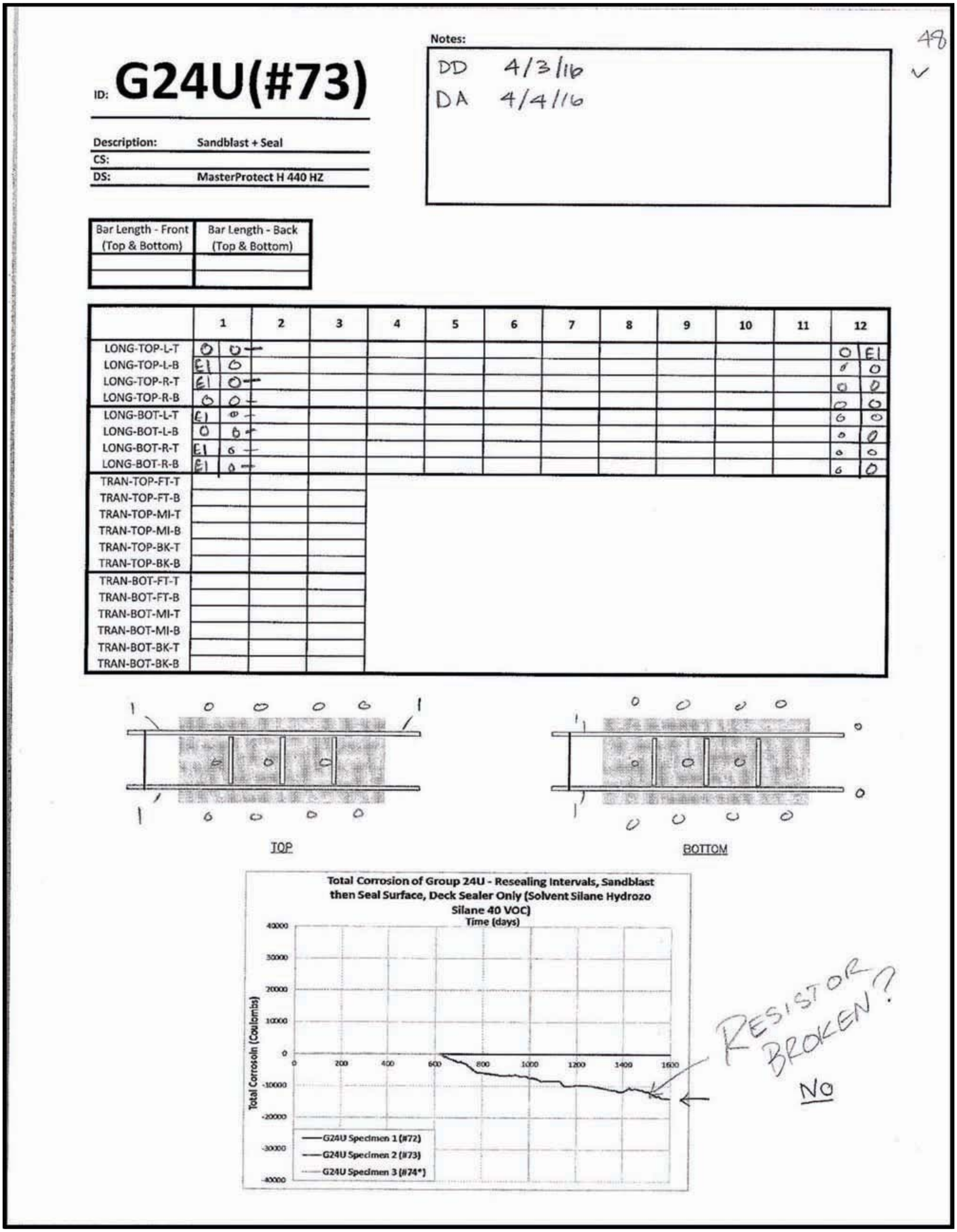


Figure C.47 Autopsy notes for Specimen No. 72.



48

ID: **G24U(#73)**

Notes:

DD 4/3/16

DA 4/4/16

Description: Sandblast + Seal

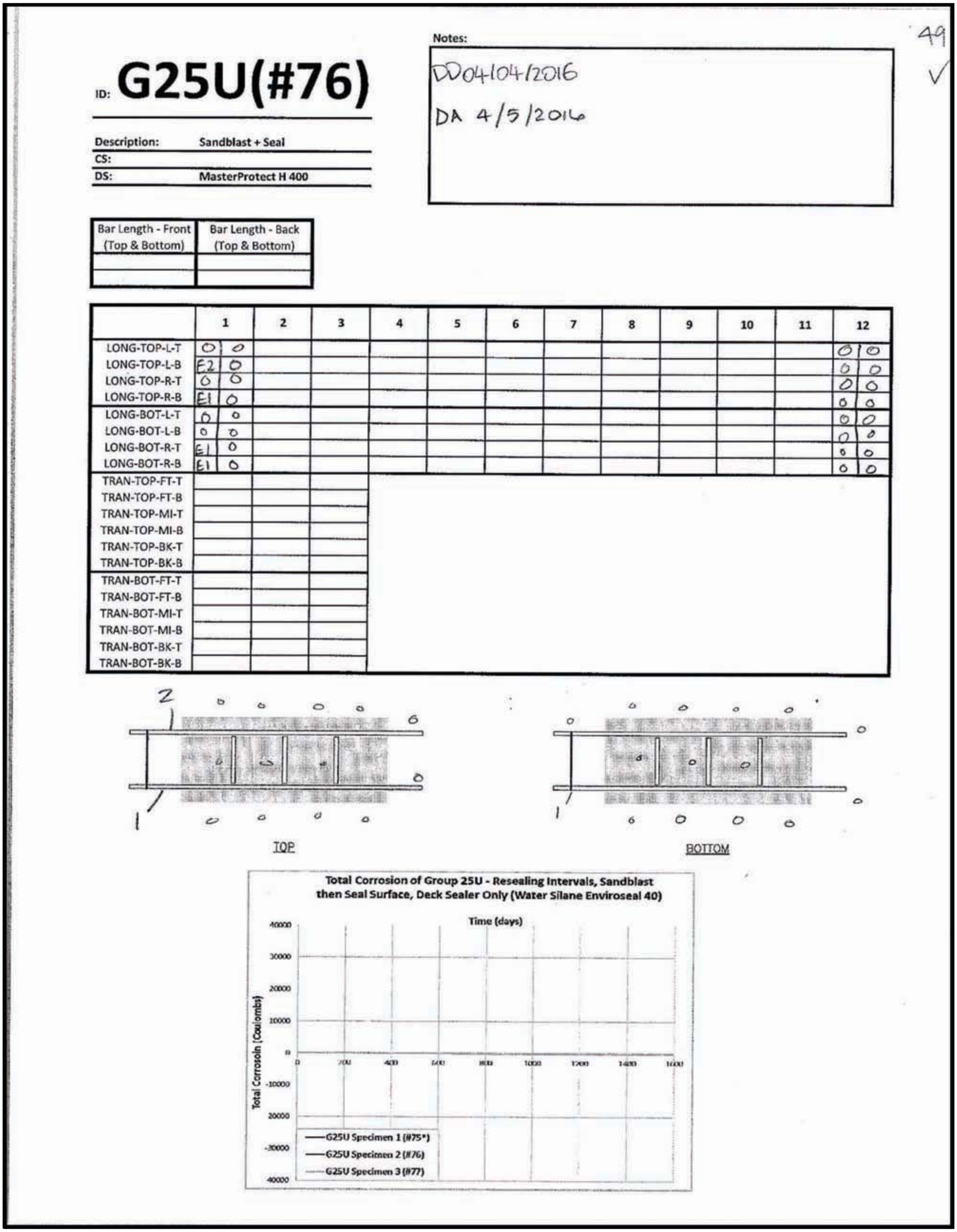
CS:

DS: MasterProtect H 440 HZ

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0											0 E1
LONG-TOP-L-B	E1 0											0 0
LONG-TOP-R-T	E1 0											0 0
LONG-TOP-R-B	0 0											0 0
LONG-BOT-L-T	E1 0											0 0
LONG-BOT-L-B	0 0											0 0
LONG-BOT-R-T	E1 0											0 0
LONG-BOT-R-B	E1 0											0 0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.48 Autopsy notes for Specimen No. 73.



49 ✓

ID: G25U(#76)

Description: Sandblast + Seal

CS:

DS: MasterProtect H 400

Notes:

DD04/04/2016

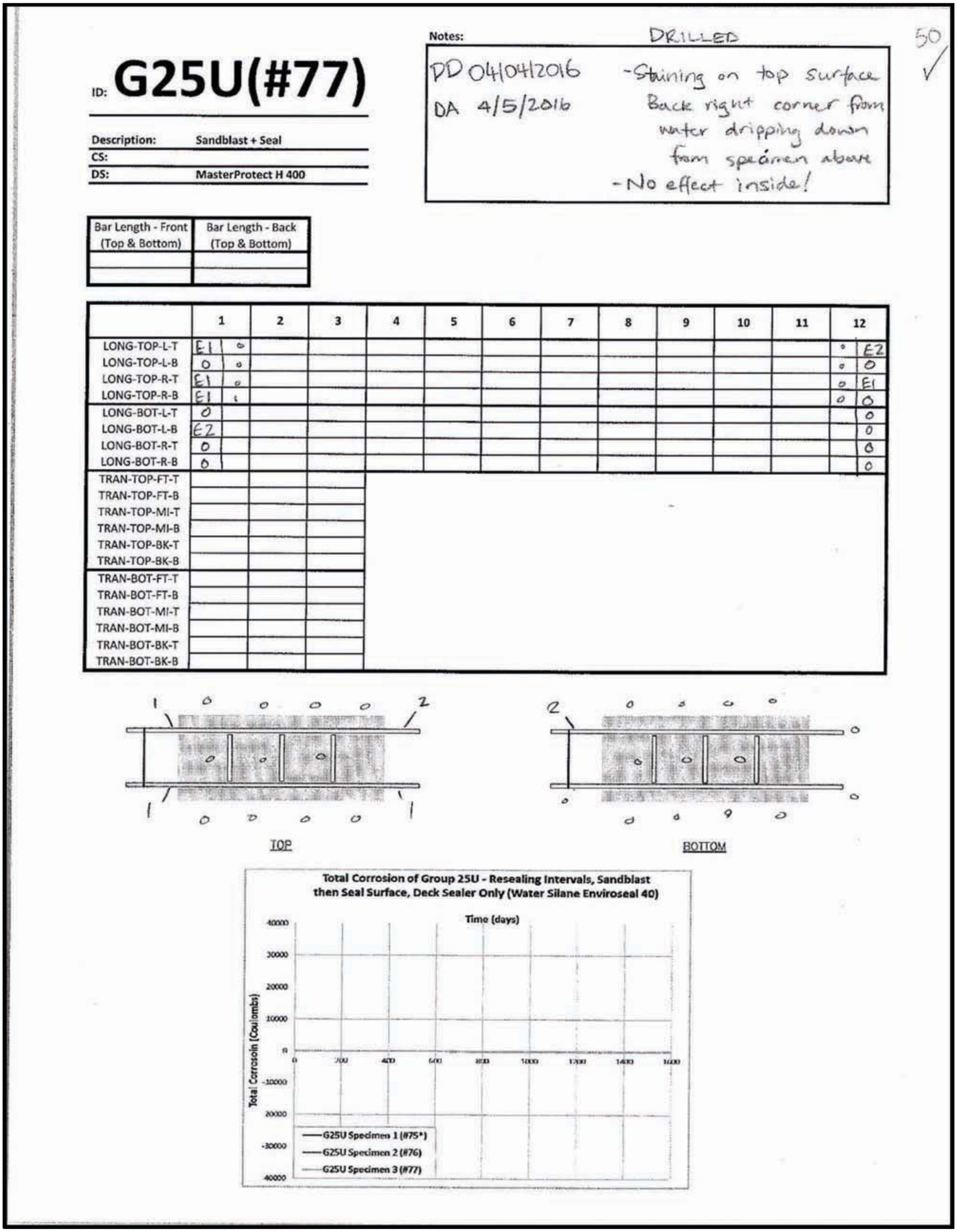
DA 4/5/2016

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1		2	3	4	5	6	7	8	9	10	11	12	
LONG-TOP-L-T	0	0											0	0
LONG-TOP-L-B	E2	0											0	0
LONG-TOP-R-T	0	0											0	0
LONG-TOP-R-B	E1	0											0	0
LONG-BOT-L-T	0	0											0	0
LONG-BOT-L-B	0	0											0	0
LONG-BOT-R-T	E1	0											0	0
LONG-BOT-R-B	E1	0											0	0
TRAN-TOP-FT-T														
TRAN-TOP-FT-B														
TRAN-TOP-MI-T														
TRAN-TOP-MI-B														
TRAN-TOP-BK-T														
TRAN-TOP-BK-B														
TRAN-BOT-FT-T														
TRAN-BOT-FT-B														
TRAN-BOT-MI-T														
TRAN-BOT-MI-B														
TRAN-BOT-BK-T														
TRAN-BOT-BK-B														

Total Corrosion of Group 25U - Resealing Intervals, Sandblast then Seal Surface, Deck Sealer Only (Water Silane Enviroseal 40)

Figure C.49 Autopsy notes for Specimen No. 76.



50 ✓

ID: **G25U(#77)**

Notes: DRILLED

PD 04/04/2016
DA 4/5/2016

- Staining on top surface Back right corner from water dripping down from specimen above
- No effect inside!

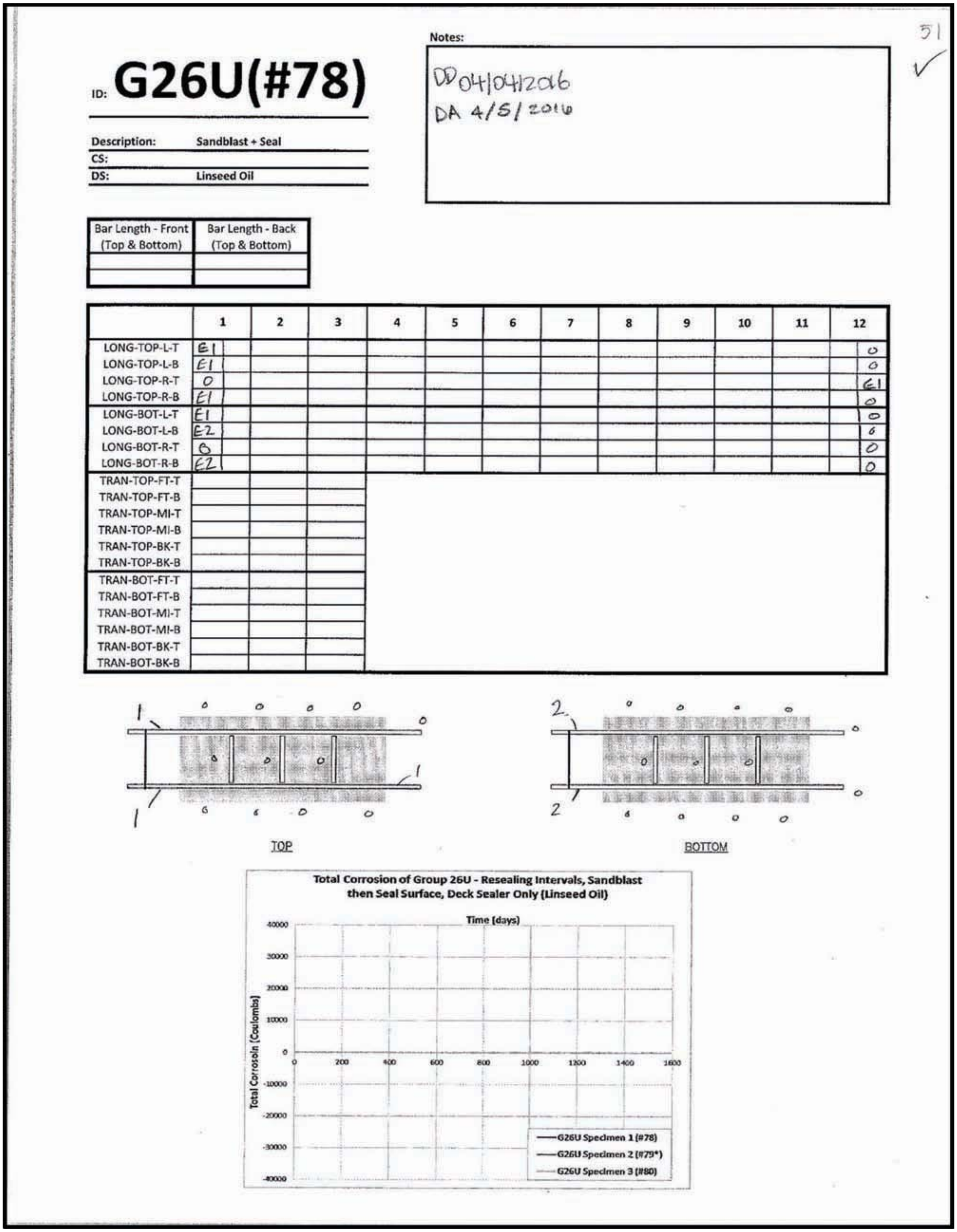
Description: Sandblast + Seal
CS:
DS: MasterProtect H 400

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 o											o E2
LONG-TOP-L-B	O o											o O
LONG-TOP-R-T	E1 o											o E1
LONG-TOP-R-B	E1 i											o O
LONG-BOT-L-T	O											O
LONG-BOT-L-B	E2											O
LONG-BOT-R-T	O											O
LONG-BOT-R-B	O											O
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Total Corrosion of Group 25U - Resealing Intervals, Sandblast then Seal Surface, Deck Sealer Only (Water Silane Enviroseal 40)

Figure C.50 Autopsy notes for Specimen No. 77.



51 ✓

ID: **G26U(#78)**

Notes:

DD 04/04/2016
DA 4/5/2016

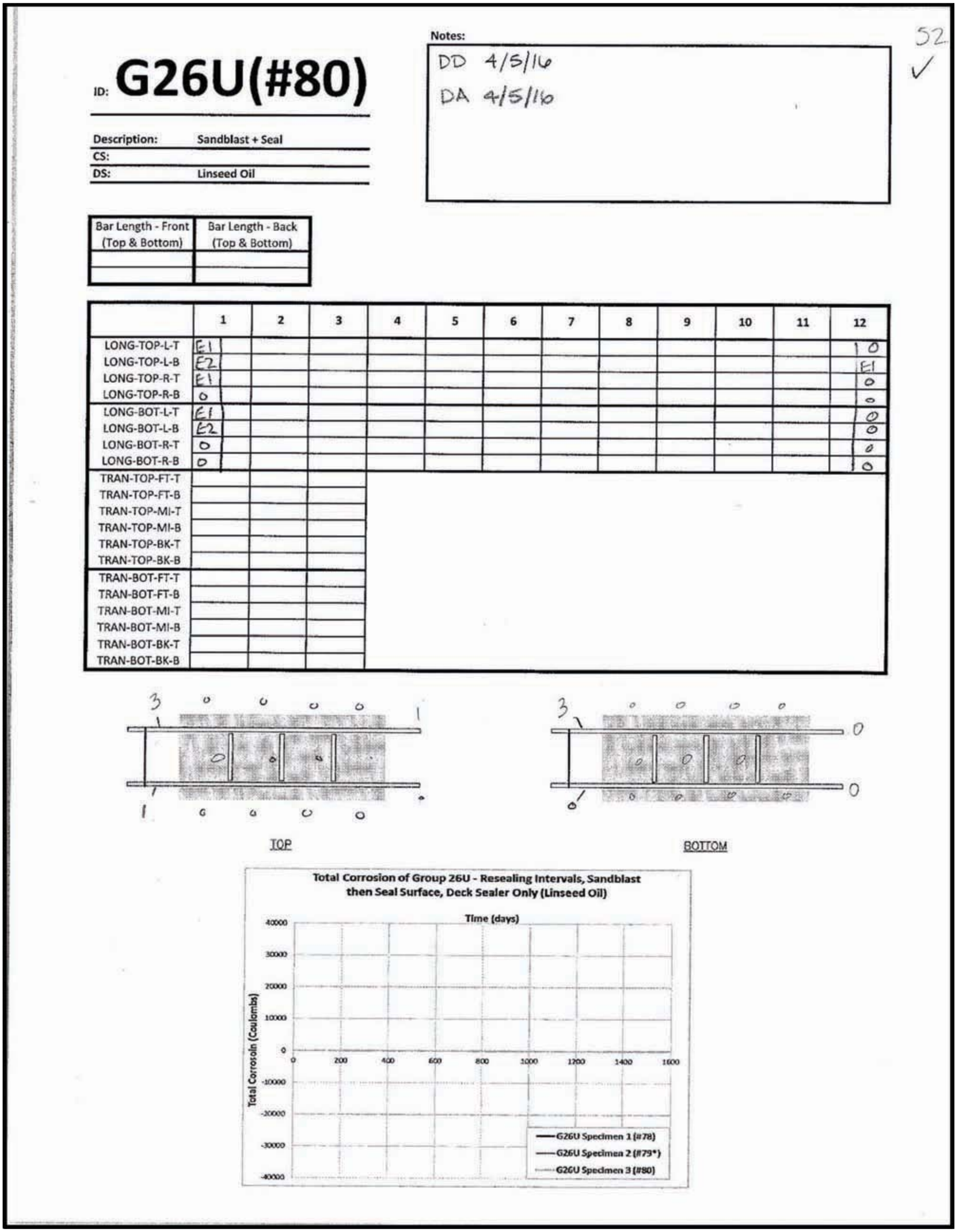
Description: Sandblast + Seal
CS:
DS: Linseed Oil

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1											0
LONG-TOP-L-B	E1											0
LONG-TOP-R-T	0											E1
LONG-TOP-R-B	E1											0
LONG-BOT-L-T	E1											0
LONG-BOT-L-B	E2											6
LONG-BOT-R-T	6											0
LONG-BOT-R-B	E2											0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Total Corrosion of Group 26U - Resealing Intervals, Sandblast then Seal Surface, Deck Sealer Only (Linseed Oil)

Figure C.51 Autopsy notes for Specimen No. 78.



ID: **G26U(#80)**

52
✓

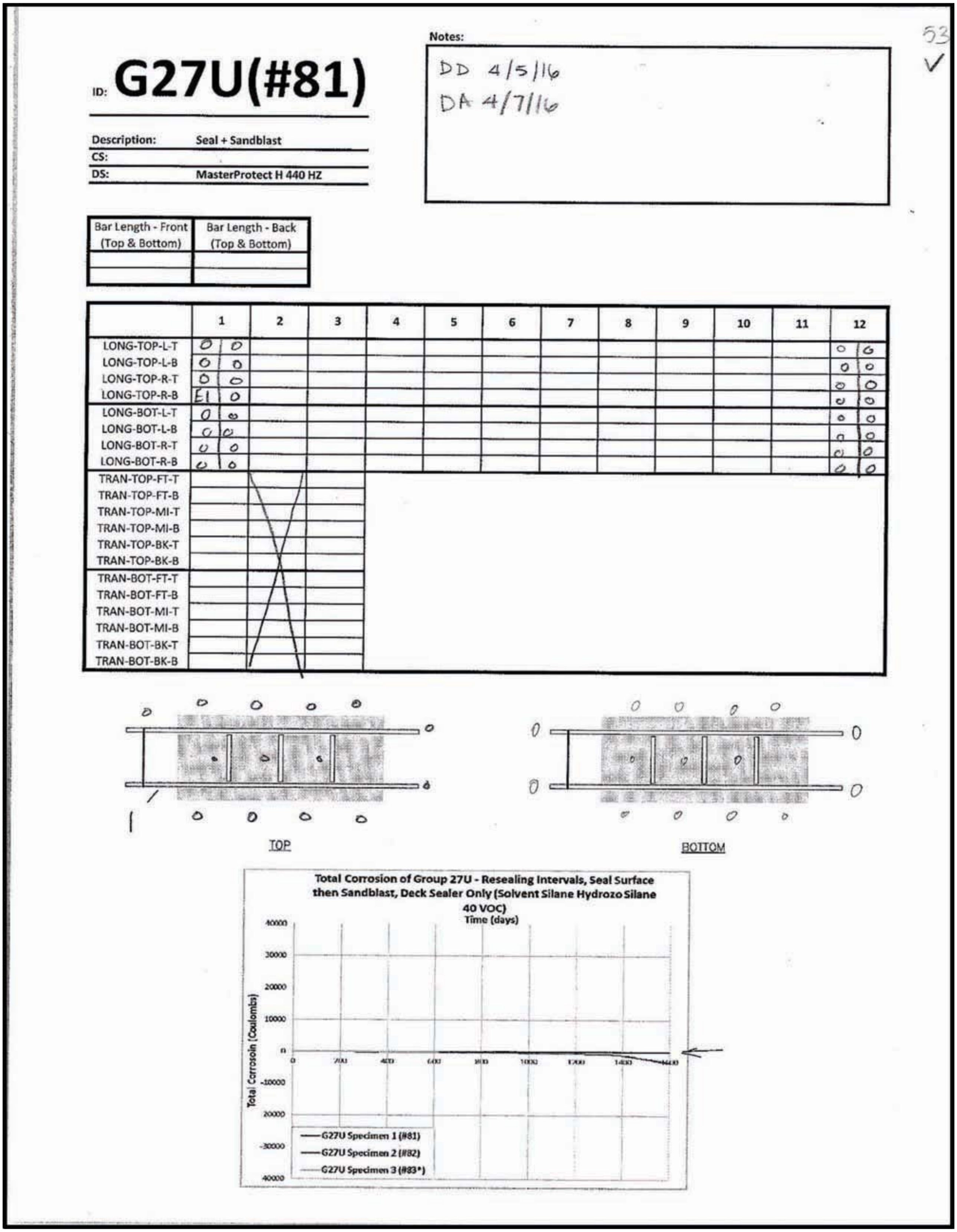
Notes:
DD 4/5/16
DA 4/5/16

Description: Sandblast + Seal
CS:
DS: Linseed Oil

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1											0
LONG-TOP-L-B	E2											E1
LONG-TOP-R-T	E1											0
LONG-TOP-R-B	0											0
LONG-BOT-L-T	E1											0
LONG-BOT-L-B	E2											0
LONG-BOT-R-T	0											0
LONG-BOT-R-B	0											0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.52 Autopsy notes for Specimen No. 80.



53 ✓

ID: **G27U(#81)**

Description: Seal + Sandblast
CS:
DS: MasterProtect H 440 HZ

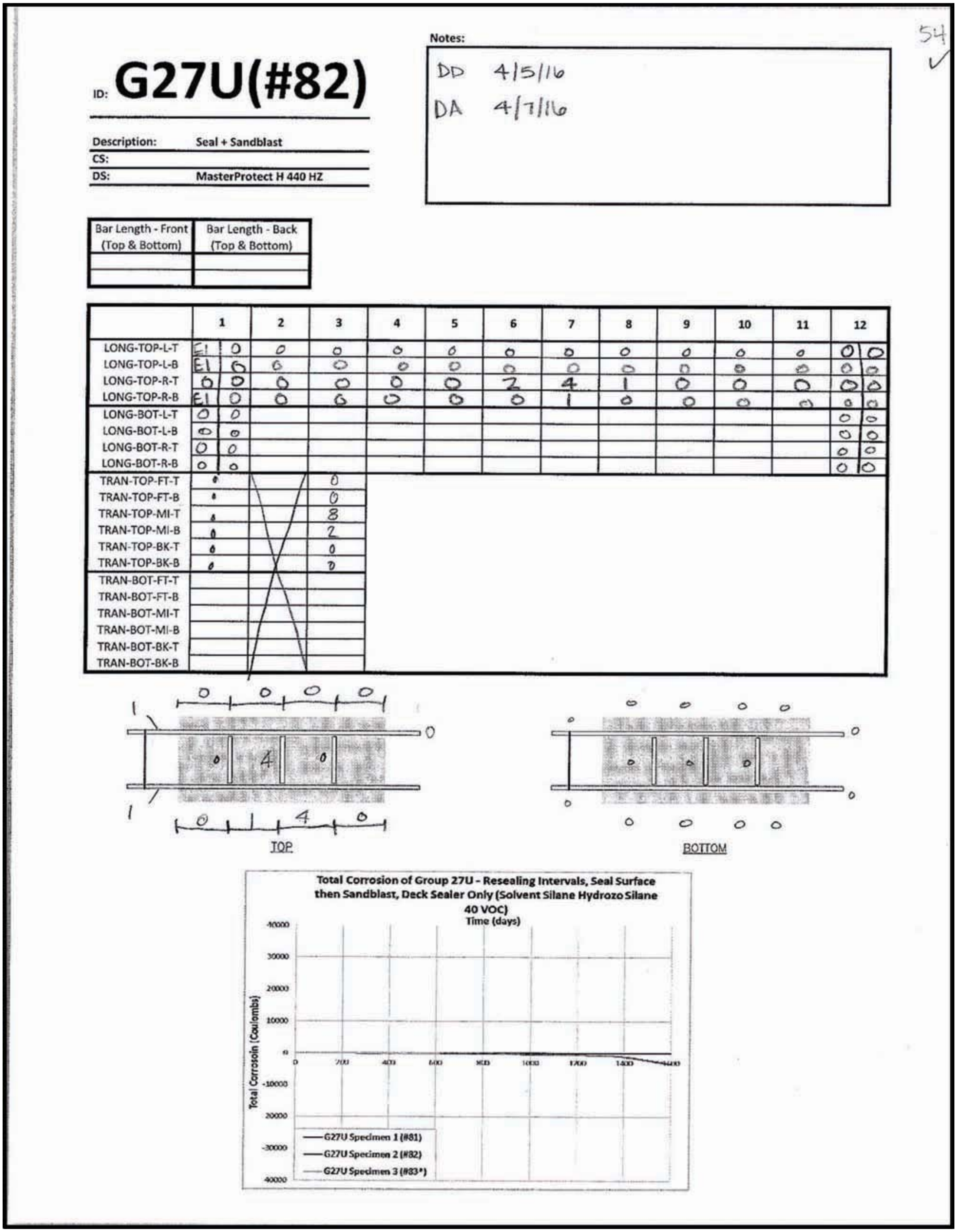
Notes:
DD 4/5/16
DA 4/7/16

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0											0 0
LONG-TOP-L-B	0 0											0 0
LONG-TOP-R-T	0 0											0 0
LONG-TOP-R-B	E1 0											0 0
LONG-BOT-L-T	0 0											0 0
LONG-BOT-L-B	0 0											0 0
LONG-BOT-R-T	0 0											0 0
LONG-BOT-R-B	0 0											0 0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Total Corrosion of Group 27U - Resealing Intervals, Seal Surface then Sandblast, Deck Sealer Only (Solvent Silane Hydrozo Silane 40 VOC)

Figure C.53 Autopsy notes for Specimen No. 81.



54 ✓

ID: **G27U(#82)**

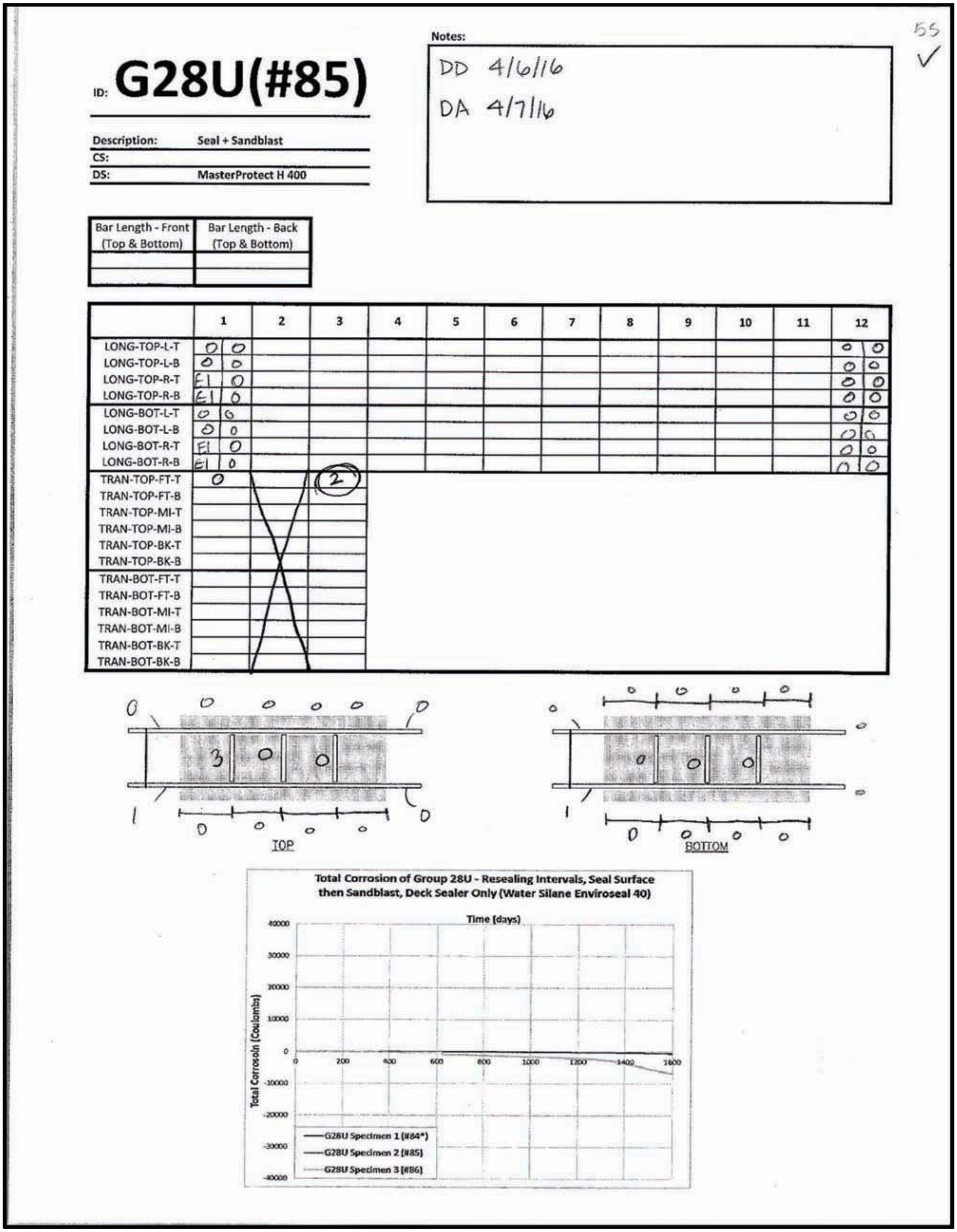
Notes:
DD 4/5/16
DA 4/7/16

Description: Seal + Sandblast
CS:
DS: MasterProtect H 440 HZ

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 0	0	0	0	0	0	0	0	0	0	0	0 0
LONG-TOP-L-B	E1 0	0	0	0	0	0	0	0	0	0	0	0 0
LONG-TOP-R-T	0 0	0	0	0	0	2	4	1	0	0	0	0 0
LONG-TOP-R-B	E1 0	0	0	0	0	0	1	0	0	0	0	0 0
LONG-BOT-L-T	0 0											0 0
LONG-BOT-L-B	0 0											0 0
LONG-BOT-R-T	0 0											0 0
LONG-BOT-R-B	0 0											0 0
TRAN-TOP-FT-T	0		0									
TRAN-TOP-FT-B	0		0									
TRAN-TOP-MI-T	0		8									
TRAN-TOP-MI-B	0		2									
TRAN-TOP-BK-T	0		0									
TRAN-TOP-BK-B	0		0									
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.54 Autopsy notes for Specimen No. 82.



55
✓

ID: **G28U(#85)**

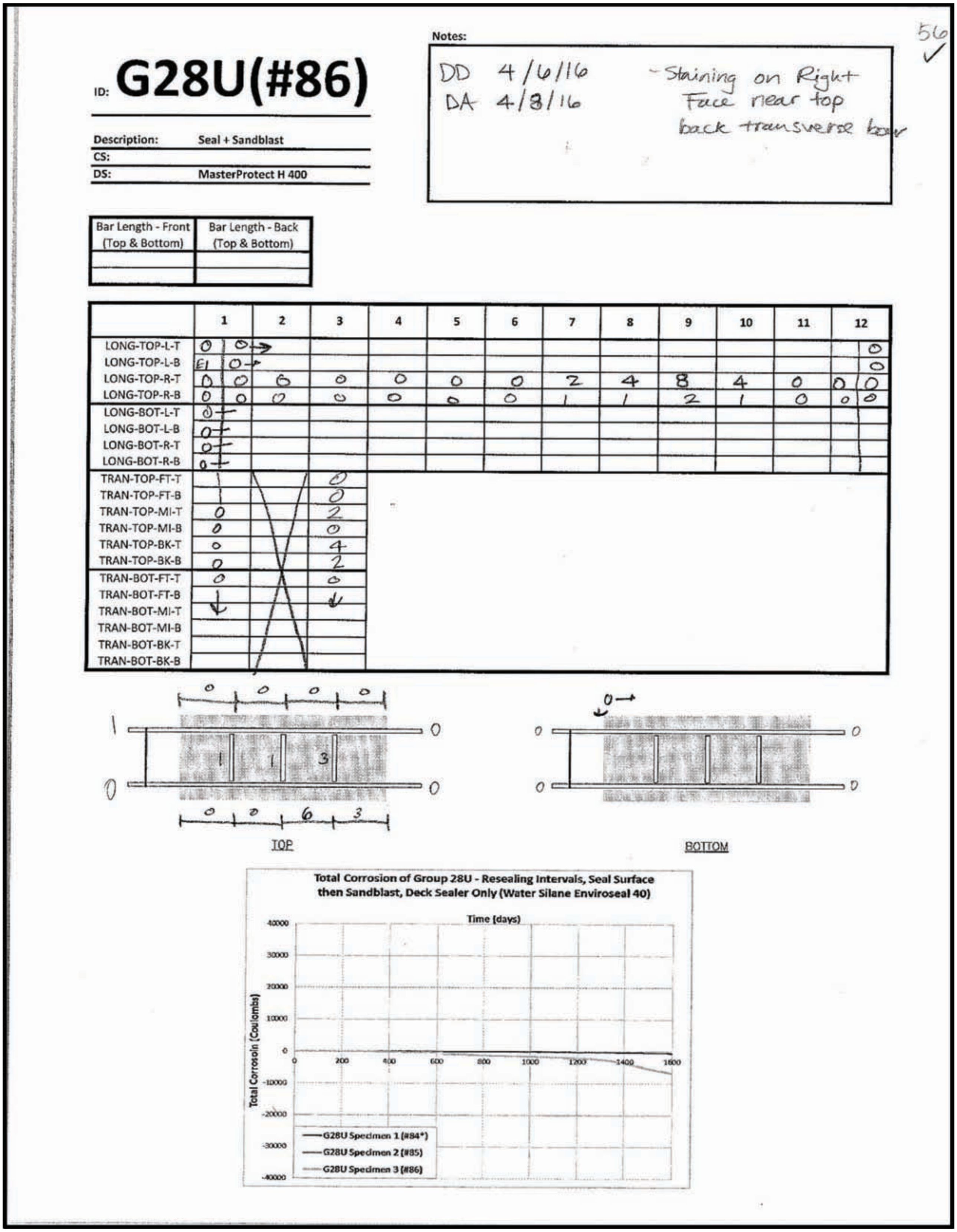
Description: Seal + Sandblast
CS:
DS: MasterProtect H 400

Notes:
DD 4/6/16
DA 4/7/16

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0											0 0
LONG-TOP-L-B	0 0											0 0
LONG-TOP-R-T	E1 0											0 0
LONG-TOP-R-B	E1 0											0 0
LONG-BOT-L-T	0 0											0 0
LONG-BOT-L-B	0 0											0 0
LONG-BOT-R-T	E1 0											0 0
LONG-BOT-R-B	E1 0											0 0
TRAN-TOP-FT-T	0		②									
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.55 Autopsy notes for Specimen No. 85.



56 ✓

ID: **G28U(#86)**

Description: Seal + Sandblast

CS:

DS: MasterProtect H 400

Notes:

DD 4/6/16
DA 4/8/16

- Staining on Right Face near top back transverse bar

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0 →											0
LONG-TOP-L-B	El 0 →											0
LONG-TOP-R-T	0 0	6	0	0	0	0	2	4	8	4	0	0 0
LONG-TOP-R-B	0 0	0	0	0	0	0	1	1	2	1	0	0 0
LONG-BOT-L-T	0											
LONG-BOT-L-B	0											
LONG-BOT-R-T	0											
LONG-BOT-R-B	0											
TRAN-TOP-FT-T			0									
TRAN-TOP-FT-B			0									
TRAN-TOP-MI-T	0		2									
TRAN-TOP-MI-B	0		0									
TRAN-TOP-BK-T	0		4									
TRAN-TOP-BK-B	0		2									
TRAN-BOT-FT-T	0		0									
TRAN-BOT-FT-B	↓		↓									
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												

Figure C.56 Autopsy notes for Specimen No. 86.

57 ✓

ID: **G29U(#87)**

Notes:

DD 4/7/16

DA 4/8/16

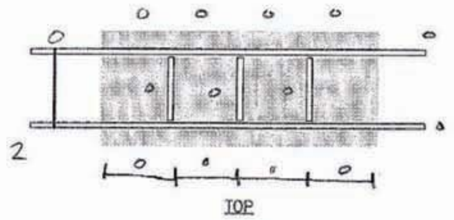
Description: Seal + Sandblast

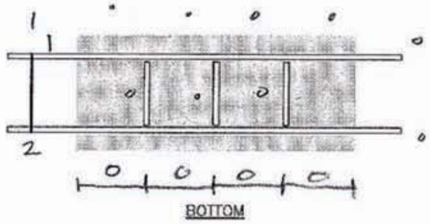
CS:

DS: Linseed Oil

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	0 0	0 →										0 9
LONG-TOP-L-B	0 0 ←											0 0
LONG-TOP-R-T	E2 0	0 →										0 0
LONG-TOP-R-B	E1 0 ←											6 0
LONG-BOT-L-T	0 0											0 0
LONG-BOT-L-B	E1 0											0 0
LONG-BOT-R-T	E2 0											0 0
LONG-BOT-R-B	0 0											0 0
TRAN-TOP-FT-T												
TRAN-TOP-FT-B												
TRAN-TOP-MI-T												
TRAN-TOP-MI-B												
TRAN-TOP-BK-T												
TRAN-TOP-BK-B												
TRAN-BOT-FT-T												
TRAN-BOT-FT-B												
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												





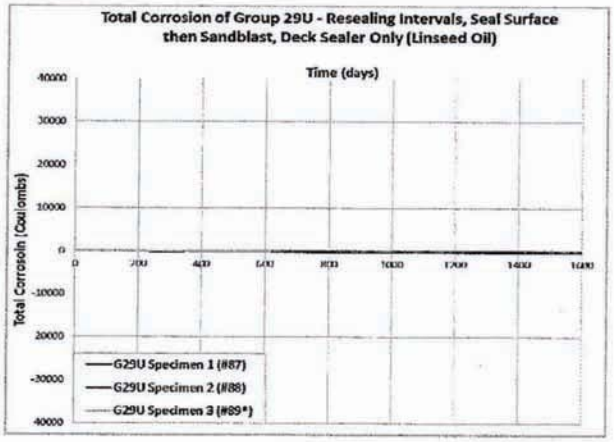
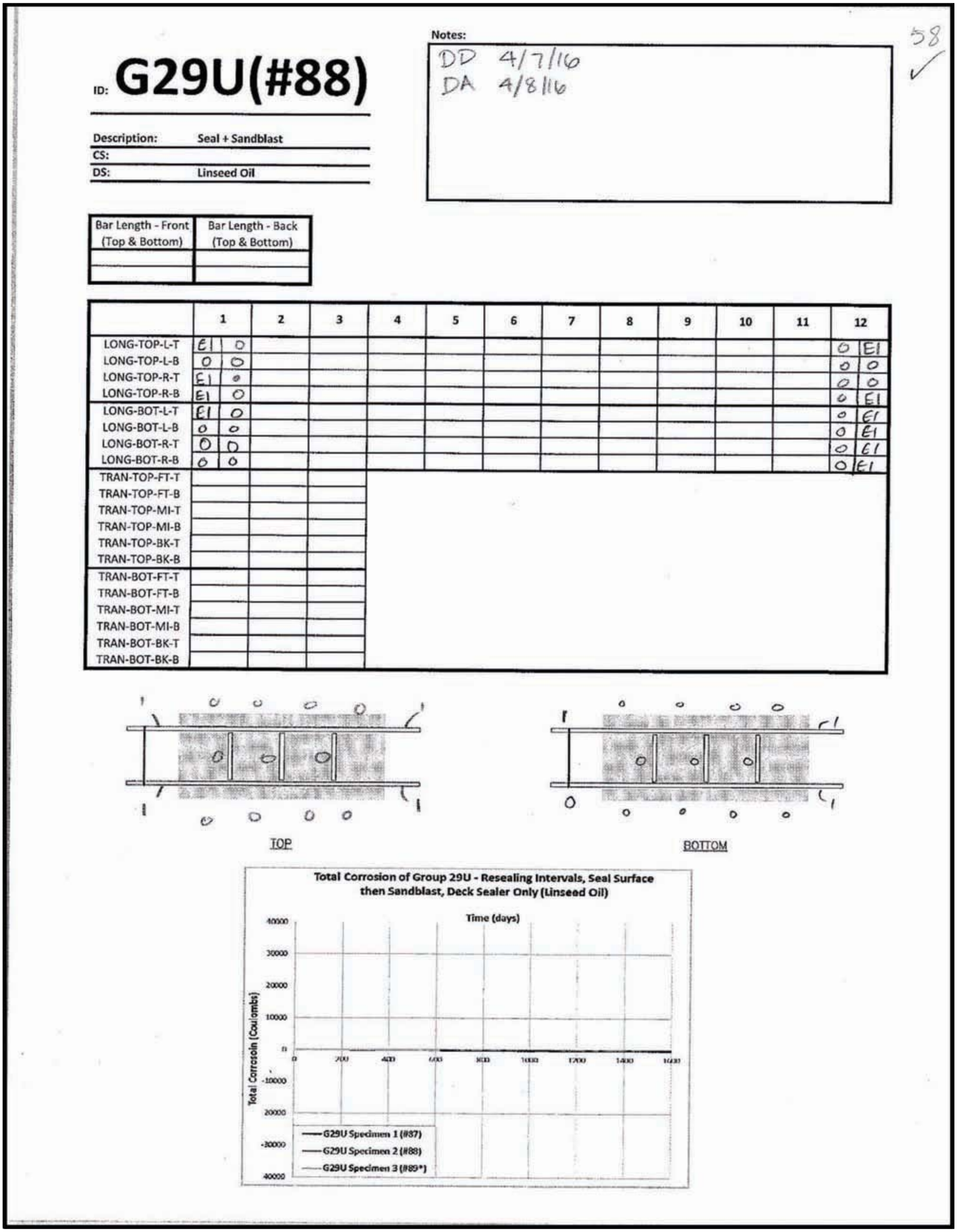


Figure C.57 Autopsy notes for Specimen No. 87.



58 ✓

ID: **G29U(#88)**

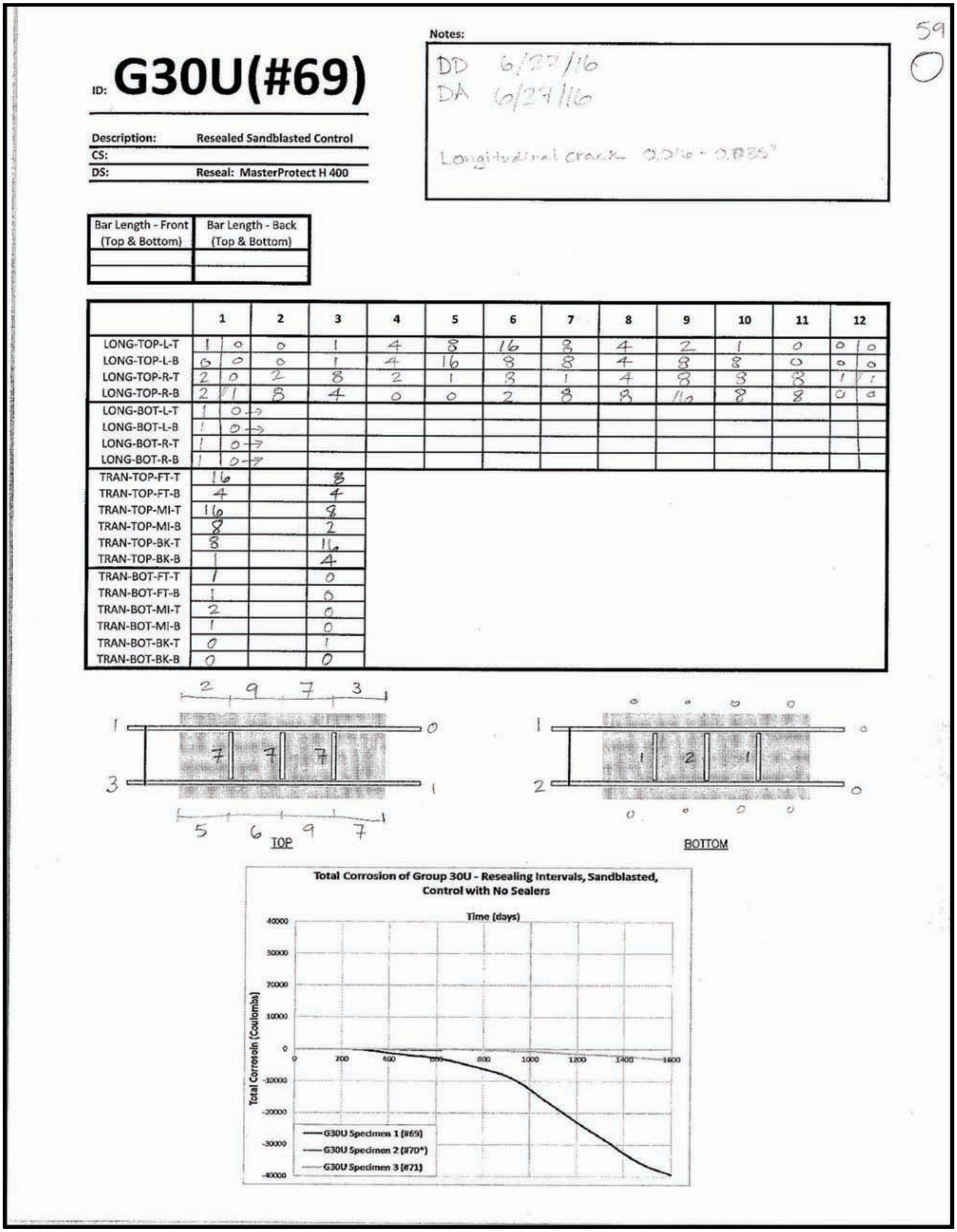
Notes:
DD 4/7/16
DA 4/8/16

Description: Seal + Sandblast
CS:
DS: Linseed Oil

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1		2	3	4	5	6	7	8	9	10	11	12	
LONG-TOP-L-T	E1	0											0	E1
LONG-TOP-L-B	0	0											0	0
LONG-TOP-R-T	E1	0											0	0
LONG-TOP-R-B	E1	0											0	E1
LONG-BOT-L-T	E1	0											0	E1
LONG-BOT-L-B	0	0											0	E1
LONG-BOT-R-T	0	0											0	E1
LONG-BOT-R-B	0	0											0	E1
TRAN-TOP-FT-T														
TRAN-TOP-FT-B														
TRAN-TOP-MI-T														
TRAN-TOP-MI-B														
TRAN-TOP-BK-T														
TRAN-TOP-BK-B														
TRAN-BOT-FT-T														
TRAN-BOT-FT-B														
TRAN-BOT-MI-T														
TRAN-BOT-MI-B														
TRAN-BOT-BK-T														
TRAN-BOT-BK-B														

Figure C.58 Autopsy notes for Specimen No. 88.



59

0

ID: **G30U(#69)**

Description: Resealed Sandblasted Control

CS:

DS: Reseal: MasterProtect H 400

Notes:

DD 6/27/16
DA 6/27/16

Longitudinal crack 0.016 - 0.035"

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	1 0	0	1	4	8	16	8	4	2	1	0	0 0
LONG-TOP-L-B	0 0	0	1	4	16	8	8	4	8	8	0	0 0
LONG-TOP-R-T	2 0	2	8	2	1	8	1	4	8	8	8	1 1
LONG-TOP-R-B	2 1	8	4	0	0	2	8	8	16	8	8	0 0
LONG-BOT-L-T	1 0 →											
LONG-BOT-L-B	1 0 →											
LONG-BOT-R-T	1 0 →											
LONG-BOT-R-B	1 0 →											
TRAN-TOP-FT-T	16		8									
TRAN-TOP-FT-B	4		4									
TRAN-TOP-MI-T	16		8									
TRAN-TOP-MI-B	8		2									
TRAN-TOP-BK-T	8		16									
TRAN-TOP-BK-B	1		4									
TRAN-BOT-FT-T	1		0									
TRAN-BOT-FT-B	1		0									
TRAN-BOT-MI-T	2		0									
TRAN-BOT-MI-B	1		0									
TRAN-BOT-BK-T	0		1									
TRAN-BOT-BK-B	0		0									

Figure C.59 Autopsy notes for Specimen No. 69.

60 ✓

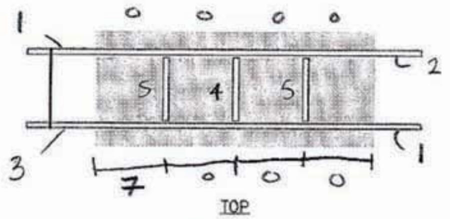
ID: **G30U(#71)**

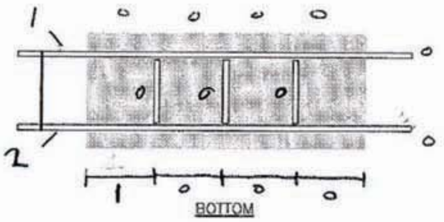
Notes:
DD 4/7/16
DA 4/9/16

Description: Sandblasted Control
CS:
DS:

Bar Length - Front (Top & Bottom)	Bar Length - Back (Top & Bottom)

	1	2	3	4	5	6	7	8	9	10	11	12
LONG-TOP-L-T	E1 0 —											0 E1
LONG-TOP-L-B	E1 0 —											0 E1
LONG-TOP-R-T	E2 2	8	4	0	0	0	0	0	0	0	0	0 E1
LONG-TOP-R-B	F2 4	2	0	0	0	0	0	0	0	0	0	0 0
LONG-BOT-L-T	0 0											0
LONG-BOT-L-B	E1 0											0
LONG-BOT-R-T	E1 1											0
LONG-BOT-R-B	E2 2											0
TRAN-TOP-FT-T	0		8									
TRAN-TOP-FT-B	0		1									
TRAN-TOP-MI-T	2		4									
TRAN-TOP-MI-B	0		1									
TRAN-TOP-BK-T	8		2									
TRAN-TOP-BK-B	1		0									
TRAN-BOT-FT-T	0		0									
TRAN-BOT-FT-B	↓		↓									
TRAN-BOT-MI-T												
TRAN-BOT-MI-B												
TRAN-BOT-BK-T												
TRAN-BOT-BK-B												





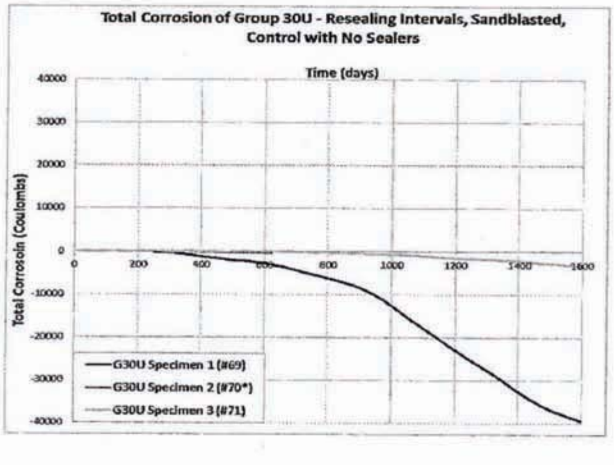


Figure C.60 Autopsy notes for Specimen No. 71.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

About This Report

An open access version of this publication is available online. This can be most easily located using the Digital Object Identifier (doi) listed below. Pre-2011 publications that include color illustrations are available online in color but are printed only in grayscale.

The recommended citation for this publication is:

Frosch, R. J., Kreger, M. E., Byl, E. A., Lyrenmann, J. P., & Pollastrini, A. S. (2016). *Development of a cost-effective concrete bridge deck preservation program: Volume 2—Final results and recommendations* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2016/23). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284316346