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Results from Accelerated Environmental Testing of Barcoded Identifiers for UF_6 Cylinders

Jim Garner
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Michael Whitaker

April 2021

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ORNL/TM-2020/1645

Nuclear Nonproliferation Division

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Prepared by
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ACRONYMS

2D	two-dimensional
CERM	CerMark-coated laser-marked stainless-steel sample
DPM	direct-part-marking
ETCH	chemically etched stainless-steel sample
GTL	Global Testing Laboratories
INMM	Institute of Nuclear Materials Management
ORNL	Oak Ridge National Laboratory
QR	quick response
REBO	Rebo premium vinyl label
TESA	laser-marked Tesa tape sample
WNTI	World Nuclear Transport Institute
YAGL	laser-marked stainless-steel sample
ZEND	Zebra Z-Endure 4000T acrylic label
ZULT	Zebra Z-Ultimate 3000T polyester label

EXECUTIVE SUMMARY

Researchers at Oak Ridge National Laboratory (ORNL) have investigated the applicability of direct part marking techniques and barcode specifications for metal nameplates attached to UF_6 cylinders. Testing in 2016 and 2017 evaluated how the size of the barcode, read distance, read angle, surface finish of the material, and marking technique influenced barcode readability as measured by commercial off-the-shelf barcode readers. This work concluded that ball-blasted stainless-steel sheets laser marked with CerMark laser marking ink offered a combination that was readable for the nominal use case. This combination of metal, surface finish of the material, and marking technique was recommended in the "Standard for UF_6 Cylinder Identification" issued in 2017 by the World Nuclear Transport Institute (WNTI).

As industry has begun to add two-dimensional barcodes to cylinders, questions are being raised regarding the readability of the barcodes over the life span of a cylinder which can exceed 40 years. To address these questions, ORNL researchers designed and conducted an accelerated environmental testing campaign to produce the environmental conditions that UF_6 cylinders often experience during typical operational and storage conditions (e.g., extreme heat, high humidity, etc.).

In planning the accelerated testing campaign, the researchers decided to evaluate six marking methods in addition to the marking method recommended in the WNTI standard for the stainless-steel nameplate, including two different methods for marking stainless steel and four types of adhesive labels. The seven sample types that were evaluated included:

- CerMark-coated laser-marked stainless-steel samples (CERM)
- Chemically etched stainless-steel samples (ETCH)
- Laser-marked stainless-steel samples (YAGL)
- Rebo premium vinyl labels (REBO)
- Laser-marked Tesa tape samples (TESA)
- Zebra Z-Endure 4000T acrylic labels (ZEND)
- Zebra Z-Ultimate 3000T polyester labels (ZULT)

This report provides the qualitative and quantitative results from the accelerated environmental testing campaign. A total of 444 samples were subjected to 10 tests that included UV, salt fog, temperature, blowing dust, high pressure and temperature water, and impact exposure. Each sample included a two-dimensional barcode and an alphanumeric string representing the cylinder identification number. When evaluating the results, primary attention was placed on the decodability of the barcodes using a barcode verifier device, since machine scanning a barcode offers the greatest efficiency and accuracy gains when reading cylinder identification numbers during safeguards activities. Contrast was considered the critical test parameter because maintaining contrast under a wide range of environmental conditions is of fundamental importance to decoding the identification number of the barcodes. Additionally, manual readability of the alphanumeric string was considered an important factor in determining whether an inspector or operator could still read the identification number of the cylinder if the barcode proved to be undecodable.

Table 1 provides a summary of the change in contrast values for each sample type after environmental testing. The contrast on average for the CerMark laser marking ink (CERM) samples, as recommended in the WNTI standard, actually improved after exposure. Zebra Z-Endure 4000T acrylic labels (ZEND) also performed very well and can be affixed to a substrate by a peel and stick application, which makes them an attractive alternative to welding or epoxying stainless-steel sheets onto a substrate.

Table 1. Summary of final contrast values for each sample type. Parentheses indicate negative change in contrast.

Sample Type	Final Difference
CERM	1.66
ZEND	0.98
ZULT	(1.51)
TESA	(1.81)
REBO	(2.30)
ETCH	(2.77)
YAGL	(3.25)

It is important to note that all the samples could be manually read after each test. In the situations where the barcode verifier could not decode the barcode, the researcher could still manually read the alphanumeric string representing the cylinder identification number. Manual readability was thus maintained as a back-up method to read the identification numbers, albeit taking more time and introducing accuracy issues such as transposition of numbers or letters when manually recording the identification number.

Importantly, the testing did show significant differences with regard to machine decodability under the test conditions, specifically with respect to maintenance of contrast. Table 13 and Table 14 in this report summarize the results for machine decodability; Table 13 summarizes the major advantages and weaknesses of each sample type across all the tests and Table 14 presents recommendations for preferred samples based on the testing results. As presented in these tables, the ball-blasted stainless-steel sheets laser marked with CerMark laser marking ink (CERM) is the most highly recommended material and marking technique identified in this testing campaign for supplemental UF_6 cylinder identifiers, as measured by the highest average change in cell contrast after environmental testing. Note that corrosion tests represented a weakness for CERM samples, though in all cases, the barcode was decoded and the alphanumeric string could be read by the researcher.

Additionally, both the Zebra Z-Endure 4000T acrylic labels (ZEND) and Zebra Z-Ultimate 3000T polyester labels (ZULT) are recommended alternatives to stainless-steel supplemental UF_6 cylinder identifiers due to their consistent symbol contrast values before and after environmental testing. While ZEND labels overall had higher symbol contrast values and a longer outdoor use rating by the manufacturer compared to ZULT labels (10 years compared to 3 years), ZEND labels must be special ordered and they exhibited printing flaws during the label creation process.

The results from the accelerated testing campaign point to a set of options for applying the WNTI standard to either newly fabricated cylinders or previously fabricated cylinders currently being used. The results reaffirm the recommendation in the WNTI standard to use a Data Matrix barcode laser-marked with CerMark laser marking ink onto a ball-blasted stainless-steel plate for new cylinders in which the identification could be marked onto the stainless-steel nameplate during fabrication. For existing cylinders, several label-type samples successfully endured the testing and offer an inexpensive, rapidly-deployable approach to applying the WNTI-recommended identification format in a manner that does not required welding or epoxying on a supplemental metal plate.

1. INTRODUCTION

Since 2011, researchers at Oak Ridge National Laboratory (ORNL) have been investigating how including machine-readable UF_6 cylinder identification features could enhance safeguards at facilities handling UF_6 cylinders. As reported in the 2017 Institute of Nuclear Materials Management paper by Garner et al. [1], the barcode size and marking technique can impact the range over which commercial off-the-shelf barcode readers can successfully decode barcodes. The 2017 paper concluded that a 1.4 in. Data Matrix barcode laser-marked with CerMark laser marking ink onto a ball-blasted stainless-steel plate would be very suitable for representative use cases involving a UF_6 cylinder global identifier. These recommendations were subsequently incorporated into the 2017 World Nuclear Transport Institute “Standard for UF_6 Cylinder Identification” [2].

This earlier work focused on Data Matrix two-dimensional (2D) barcodes (Figure 1). Data Matrix and Quick Response (QR) are two of the most widely used 2D barcode symbologies and can be printed on labels or directly marked on parts. The specifications and quantifiable grading procedures for these 2D barcodes are covered by several standards:

- ISO/IEC 16022, “Data Matrix bar code symbology specification” [3]
- ISO/IEC 18004, “QR code bar code symbology specification” [4]
- ISO/IEC 15415, “2-D bar code print quality standard [5],” which incorporated and expanded upon marking quality definitions from ISO/IEC 16022 and ISO/IEC 18004
- AIM DPM-1-2006, verification standard for direct part marking (DPM) 2D code image quality established by the Automatic Identification Manufacturers based on ISO/IEC 15415:2004
- ISO/IEC TR 29158, verification standard for DPM 2D code image quality adopted by International Organization for Standardization [6], which was based on AIM DPM-1-2006 and incorporated ISO/IEC15415:2011

QR Code   Data Matrix

Figure 1. Examples of QR and Data Matrix 2D barcodes.

Figure 2 illustrates the relationship between the standards that govern 2D barcodes. Data Matrix barcodes are considered better than QR codes for industrial applications because they have higher error correction. Many 2D barcode symbologies include error correction. The 14 × 14 module Data Matrix barcodes, as recommended by World Nuclear Transport Institute, include 28%–39% error correction [7]. QR codes have four error correction levels, but they have a maximum of 30% error correction.

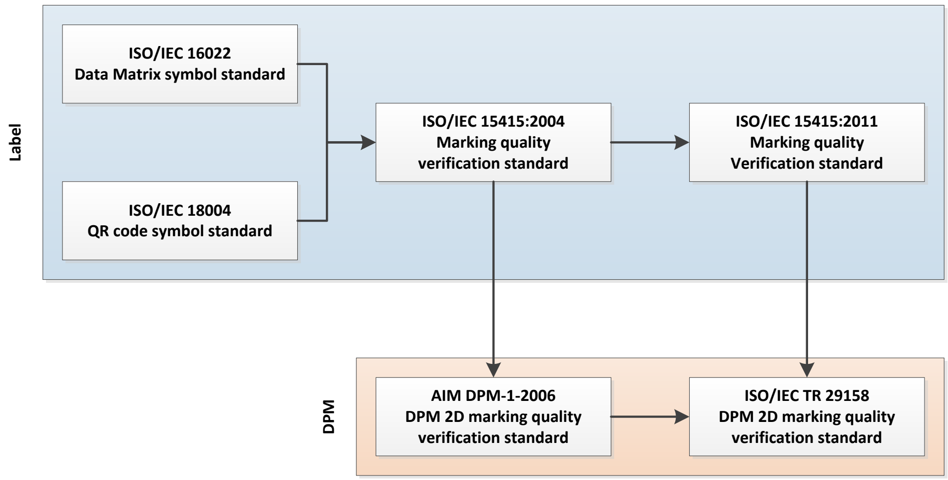


Figure 2. Multiple standards apply to 2D barcodes and barcode verification.

2. PURCHASE AND PREPARATION OF BARCODE SAMPLES

The ORNL team collected and prepared approximately 630 barcode samples and labels for accelerated environmental testing. Seven different types of barcoded identifiers were evaluated:

- CerMark-coated laser-marked stainless-steel samples (CERM)
- Chemically etched stainless-steel samples (ETCH)
- Laser-marked stainless-steel samples (YAGL)
- Rebo premium vinyl labels (REBO)
- Laser-marked Tesa tape samples (TESA)
- Zebra Z-Endure 4000T acrylic labels (ZEND)
- Zebra Z-Ultimate 3000T polyester labels (ZULT)

The CERM samples were purchased from Automation-Plus at a cost of $22.00 each for a quantity of 100. These samples were prepared from 13 gauge (0.0897 in.) 304 stainless sheet that was ball blasted, coated with the CerMark laser marking ink, laser marked using a YAG laser system, and then cleaned to remove the unbonded material.

The ETCH samples were purchased from American Nameplate at a cost of $23.50 each for a quantity of 100 plus. These samples were prepared from 13 gauge (0.0897 in.) 304 stainless sheet that was ball blasted by Automation-Plus then shipped to American Nameplate as 18 × 16 in. sheets. The sheets were then chemically etched to a depth of approximately 0.005 in. Paint was applied to the surface and squeegeed to leave paint only in the etched markings. The samples were then cut from the larger sheets using a water jet.

The YAGL samples were also purchased from Automation-Plus at a cost of $17.50 each for a quantity of 100. These samples were prepared from 13 gauge (0.0897 in.) 304 stainless sheet that was ball blasted and then laser marked using a YAG laser system.

The REBO labels were provided complementary by ZingGreen Safety Products, one of the U.S. distributors for the REBO printers. The vendor used a Rebo thermal printer (e.g., SMS430) with Rebo Premium Industrial Vinyl labels (i.e., ST700) and industrial print ribbon (i.e., SR10).

The TESA samples were purchased from Code Source at a cost of $4.36 each for a quantity of 100. These labels were manufactured from Tesa Secure 6973 tape, which is a 118 µm/4.6 mil thick double layer, brittle, acrylic film with 25 g/m^2 resin modified acrylic adhesive [8]. The vendor promoted these labels as being "as robust as metal" once applied.

ORNL researchers printed the ZEND samples using a Zebra ZT410 thermal transfer printer onto Zebra Z-Endure 4000T acrylic label material using Zebra 5100 Premium ribbon. The manufacturer markets Z-Endure 4000T as a special label material offering 10-year outdoor durability. This material is typically only available by special order and is subject to nonrecurring engineering charges (e.g., die fee) and a minimum purchase quantity. If these obstacles can be surmounted, we estimate the cost for a 2 × 4 in. label to be approximately $0.15 each. The Z-Endure 4000T material is a 2.0 mil acrylic with a 0.8 mil acrylic adhesive. The Z-Endure 4000T is advertised to offer a service temperature of −40°F to 212°F (−40°C to 100°C). The manufacturer reports testing this material using a QUV accelerated weathering tester for 10,000 hours alternating between 8 hours of UV exposure at 60°C and 4 hours of condensation at 50°C. The manufacturer reported no degradation after 5,000 hours and very slight chalking after 10,000 hours. This test procedure appears similar to Tests 2 and 3 described in this report, but the manufacturer does not include sufficient details about the type of UV bulb or irradiance to directly compare the manufacturer's results with this report's results. [9]

Note that the authors had trouble printing faultless barcodes using the Zebra Z-Endure 4000T acrylic label material. As shown in Figure 3 white streaks were observed in the dark modules, especially in the finder pattern shown on the left of the Data Matrix barcode.

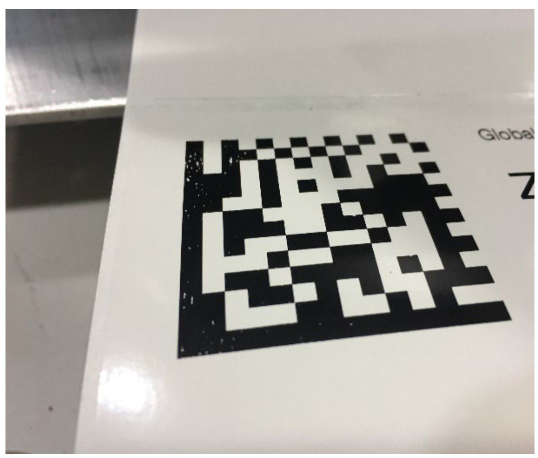


Figure 3. Z-Endure 4000T labels with white specs in the dark modules. These labels were printed at ORNL using a Zebra ZT410 thermal transfer printer with 5100 premium resin.

The researchers printed the ZULT samples using a Zebra ZT410 thermal transfer printer onto Zebra Z-Ultimate 3000T acrylic label material using Zebra 5100 Premium ribbon. These samples could be purchased preprinted for approximately $0.27 each for a quantity of 100 or printed on-premise for about $0.08 each excluding the cost of the ~$1,500 printer. Z-Ultimate 3000T is 2.0 mil polyester with 0.8 mil acrylic-based adhesive. The manufacturer advertises the Z-Ultimate has a 3 year expected exterior life with a service temperature from −40°F to 302°F (−40°C to 150°C) [10]. Despite using the same printer and the same printing ribbon, the authors did not observe the white flecks in ZULT samples that the authors experienced with the ZEND samples.

Of the 630 barcode samples that were prepared, 444 were selected for environmental testing; the remaining 186 barcode samples were saved as backups. Most of these barcode samples were welded, epoxied, or self-adhered to ½ in. thick A516 steel coupons, which is the same steel alloy and thickness used to manufacture model 30B UF_6 cylinders. ORNL purchased 4 ft × 8 ft A516 sheets with a mill finish, and ORNL machinists laser-cut the sheets into smaller 3 in. × 6 in. coupons. All coupons were then sandblasted, and a subset of the sandblasted coupons were further polished to fully remove the mill finish for welding.

Of the stainless-steel barcode samples (CERM, ETCH, YAGL), 45 were welded to polished coupons, and 116 were affixed to the coupons using Aremco 517 epoxy.[1] The epoxy preparation process is described in Appendix A. Of the 116 stainless-steel barcode samples epoxied to the coupons, 19 were epoxied to polished coupons, and 97 were epoxied to sandblasted-only coupons. The remaining 105 stainless-steel barcode samples that were not attached to coupons were considered “free.”

The label-type barcode samples (REBO, TESA, ZEND, ZULT) were equipped with an adhesive backing. Twenty-four of the label-type barcode samples were self-adhered to polished coupons and 154 were self-adhered to sandblasted-only coupons. There were no welded or “free” label-type barcode samples. A selection of stainless-steel and label-type barcode samples are shown in Figure 4 and Figure 5, respectively.

Figure 4. Chemically etched stainless-steel barcode sample, no coupon attachment (free).

Figure 5. Rebo premium vinyl label self-adhered to a sandblasted coupon.

The number of tested stainless-steel (CERM, ETCH, YAGL) and label-type (REBO, TESA, ZEND, ZULT) barcode samples prepared using each coupon attachment method is provided in Table 2. The identification number, environmental test information, and coupon attachment method for individual samples are displayed in Appendix B.

[1] This epoxy has been used by other UF_6 industry members to adhere new placards to the skirt of cylinders. This type of epoxy may be an attractive alternative for industry compared to welding because it may be a permanent way to adhere the global identifier to the front face of UF_6 cylinders without requiring an R-stamp welder during the recertification process.

Table 2. Number of Samples tested for each barcode types and coupon attachment method combination.

Coupon Finish (Attachment Method)	Barcode Sample Type						
	Stainless Steel (266 total)			Label (178 total)			
	CERM	ETCH	YAGL	REBO	TESA	ZEND	ZULT
Polished (Welded)	15	15	15	0	0	0	0
Polished (Epoxied)	7	6	6	0	0	0	0
Polished (Self-Adhered)	0	0	0	6	6	6	6
Sandblasted-Only (Epoxied)	31	33	33	0	0	0	0
Sandblasted-Only (Self-Adhered)	0	0	0	42	42	28	42
Free	34	33	38	0	0	0	0
Total Number of Samples	87	87	92	48	48	34	48

3. QUANTITATIVE METRIC BARCODE VERIFICATION MEASUREMENT

The ORNL team used a Webscan TruCheck DPM Tower to scan the barcode samples (Figure 6). The DPM Tower is a barcode verifier that grades 2D barcodes directly marked on a sample using ISO 29158 (AIM-DPM) and 2D barcodes printed on label material using ISO 15415. The chemically etched (ETCH), laser-marked (YAGL, TESA), and CerMark-coated laser-marked (CERM) barcodes were DPM-type barcodes and were thus graded using ISO 29158, but the Rebo (REBO) and Zebra (ZEND, ZULT) barcode samples were graded using ISO 15415.

Figure 6. Webscan TruCheck DPM Tower.

ORNL configured the barcode verifier to produce a PDF report and a .CSV summary file for each scan. As shown in Figure 7, the PDF report includes summary information at the top that provides the data, symbology, and grades for any tests selected.

Webscan TruCheck™ USB Verification Report

Software Version: 3.03.54, Unit Serial: TC-825-0318-121

Verified: Tue 16-Apr-2019 03:01:04 PM, Last Calibrated: Tue 16-Apr-2019 11:59:30 AM

Page 1 of 2

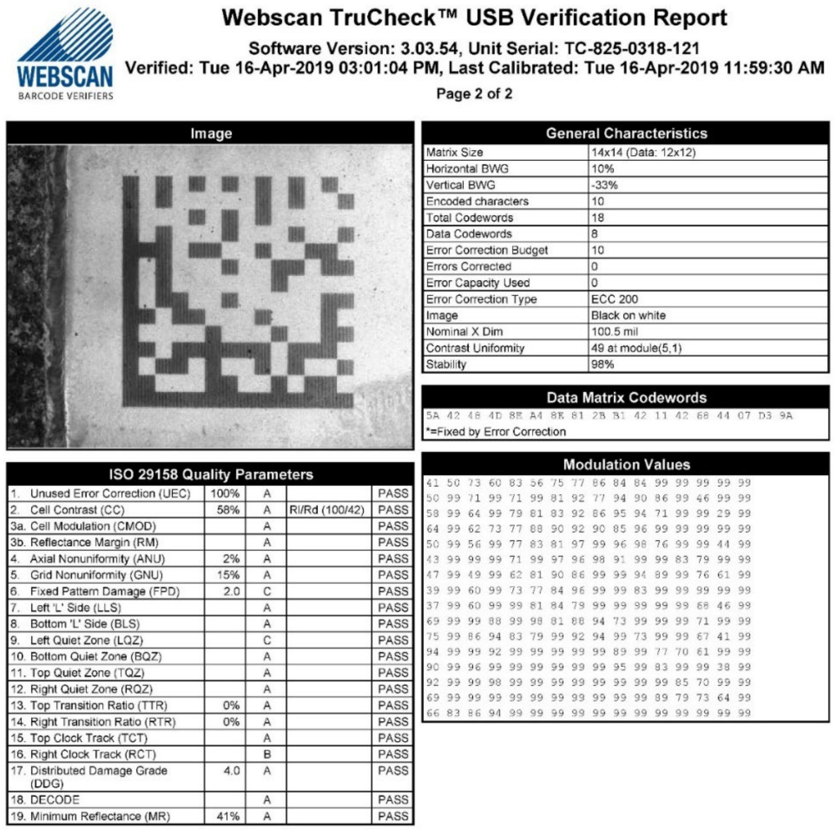
Report Summary	
Data	YAGL123412
Symbology	DataMatrix
Verified By	ORNL_Admin

Verification Grades

Standard	Grade	Aperture	Wavelength	Lighting	Formal Grade	Notes
ISO15415	F (0.0)	20	660	45	0.0/20/660/45	
ISO29158 (AIM-DPM)	C (2.0)	81	660	45Q	DPM 2.0/81/660/45Q	[Warning]Symbol X-Dimension out of range

Figure 7. Top portion of Webscan Verification Report for YAGL123412 after QUV and Q-FOG testing.

ORNL recorded results for both ISO 15415 and ISO 29158 for each sample; however, the ISO 15415 results are only meaningful for the Rebo and Zebra label barcode samples (REBO, ZEND, and ZULT), and the ISO 29158 results are only meaningful for the DPM barcode samples (CERM, ETCH, YAGL, and TESA). Figure 8 shows an example ISO 29158 results for a laser-marked stainless-steel sample (YAGL123412) that was part of Test 4 (QUV and Q-FOG testing). Details about the key metrics that changed for YAGL123412 after environmental exposure are discussed in Garner et al. [11].



Webscan TruCheck™ USB Verification Report

Software Version: 3.03.54, Unit Serial: TC-825-0318-121

Verified: Tue 16-Apr-2019 03:01:04 PM, Last Calibrated: Tue 16-Apr-2019 11:59:30 AM

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WEBSCAN BARCODE VERIFIERS

Image

General Characteristics	
Matrix Size	14x14 (Data: 12x12)
Horizontal BWG	10%
Vertical BWG	-33%
Encoded characters	10
Total Codewords	18
Data Codewords	8
Error Correction Budget	10
Errors Corrected	0
Error Capacity Used	0
Error Correction Type	ECC 200
Image	Black on white
Nominal X Dim	100.5 mil
Contrast Uniformity	49 at module(5,1)
Stability	98%

Data Matrix Codewords

5A 42 48 4D 8E A4 8E 81 2B B1 42 11 42 68 44 07 D3 9A

*=Fixed by Error Correction

ISO 29158 Quality Parameters				
1. Unused Error Correction (UEC)	100%	A		PASS
2. Cell Contrast (CC)	58%	A	Rl/Rd (100/42)	PASS
3a. Cell Modulation (CMOD)		A		PASS
3b. Reflectance Margin (RM)		A		PASS
4. Axial Nonuniformity (ANU)	2%	A		PASS
5. Grid Nonuniformity (GNU)	15%	A		PASS
6. Fixed Pattern Damage (FPD)	2.0	C		PASS
7. Left 'L' Side (LLS)		A		PASS
8. Bottom 'L' Side (BLS)		A		PASS
9. Left Quiet Zone (LQZ)		C		PASS
10. Bottom Quiet Zone (BQZ)		A		PASS
11. Top Quiet Zone (TQZ)		A		PASS
12. Right Quiet Zone (RQZ)		A		PASS
13. Top Transition Ratio (TTR)	0%	A		PASS
14. Right Transition Ratio (RTR)	0%	A		PASS
15. Top Clock Track (TCT)		A		PASS
16. Right Clock Track (RCT)		B		PASS
17. Distributed Damage Grade (DDG)	4.0	A		PASS
18. DECODE		A		PASS
19. Minimum Reflectance (MR)	41%	A		PASS

Modulation Values															
41	50	73	60	83	56	75	77	86	84	84	99	99	99	99	99
50	99	71	99	71	99	81	92	77	94	90	86	99	46	99	99
58	99	64	99	79	81	83	92	86	95	94	71	99	99	29	99
64	99	62	73	77	88	90	92	90	85	96	99	99	99	99	99
50	99	56	99	77	83	81	97	99	96	98	76	99	99	44	99
43	99	99	99	71	99	97	96	98	91	99	99	83	79	99	99
47	99	49	99	62	81	90	86	99	99	94	89	99	76	61	99
39	99	60	99	73	77	84	96	99	99	83	99	99	99	99	99
37	99	60	99	99	81	84	79	99	99	99	99	99	68	46	99
69	99	99	88	99	98	81	88	94	73	99	99	99	71	99	99
75	99	86	94	83	79	99	92	94	99	73	99	99	67	41	99
94	99	99	92	99	99	99	99	99	89	99	77	70	61	99	99
90	99	96	99	99	99	99	99	99	95	99	83	99	99	38	99
92	99	99	98	99	99	99	99	99	99	99	99	85	70	99	99
69	99	99	99	99	99	99	99	99	99	99	89	79	73	64	99
66	83	86	94	99	99	99	99	99	99	99	99	99	99	99	99

Figure 8. Bottom portion of Webscan Verification Report for YAGL123412 after QUV and Q-FOG testing. This portion of the report displays the ISO 29158 quality parameters.

ACCELERATED ENVIRONMENTAL TESTS

A series of 10 tests were designed to produce environmental conditions that UF_6 cylinders may experience during their life cycle which can exceed 40 years. As summarized in Table 3 and further described in the following sections, four tests were conducted at Q-Lab in Homestead, Florida, one test was conducted at ORNL, and five tests were conducted at Global Testing Laboratories (GTL) in Knoxville, Tennessee.

Table 3. Environmental Test Summary.

Test Number	Environmental Test	Testing Location	Dates (2019)	Number of Samples		
				Stainless-Steel	Label-Type	Total
1	Q-SUN Xenon Arc Lamp	Q-Lab	Feb.–Mar.	10	12	22
2	QUV UVA	Q-Lab	Feb.–Mar.	12	12	24
3	QUV UVB	Q-Lab	Feb.–Mar.	12	12	24
4	QUV and Q-FOG	Q-Lab	Feb.–Mar.	12	12	24
5	Temperature	ORNL	Feb.–Apr.	37	24	61
6	Cyclic Corrosion	GTL	Jan.–Jun.	41	22	63
7	Corrosion	GTL	Jan.–Jun.	36	21	57
8	Blowing Sand/Dust	GTL	Jan.–Jun.	37	20	57
9	Impact	GTL	Jan.–Jun.	34	21	55

10	Pressure and Temperature Water Jet	GTL	Jan.–Jun.	36	21	57

4.1 Q-SUN XENON ARC LAMP TESTING (TEST 1)

Q-Lab staff installed 22 barcode samples into a Q-SUN Xe-3 xenon arc lamp chamber as shown in Figure 9 and Figure 10. This chamber exposed samples to light with humidity control and a water spray, replicating sunlight and rain conditions. Testing followed a cycle like Cycle 1 in ASTM G155, "Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials." An irradiance of 0.55 W/m^2 at 340 nm and the "daylight - Q" filters were used [12]. Samples were exposed to 102 min of light at 63°C black panel temperature, then to 18 min of light and water spray. This cycle was repeated for a total 500 h. A comprehensive list of samples subjected to Q-SUN xenon arc lamp testing is included in Appendix C.

Figure 9. Barcode samples were tested for 500 h in a Q-SUN Xe-3 Xenon arc lamp chamber.

Figure 10. Barcode samples on Q-SUN Xe-3 Xenon arc lamp chamber loading tray.

4.2 QUV UVA TESTING (TEST 2)

Q-Lab staff installed 24 barcode samples into a QUV accelerated weathering chamber with UVA bulbs as shown in Figure 11 and Figure 12. This test replicated sunlight and dew weather conditions and followed a cycle like Cycle 1 in ASTM G154, “Standard Practice for Operating Fluorescent Ultraviolet (UV) lamp Apparatus for Exposure of Nonmetallic Materials.” Samples were exposed to 8 h of light at 60°C black panel temperature followed by 4 h of condensation at 50°C black panel temperature. These cycles were repeated for a total of 500 h. Fluorescent UVA-340 bulbs at 340 nm were used with an irradiance of 0.89 W/(m^2 • nm) [13]. A comprehensive list of samples subjected to QUV UVA testing is included in Appendix C. As a point of reference, Zebra suggests that 8 h of QUV exposure at 60°C, followed by 4 h at 50°C for a total of 1,000 h is representative of about 1 year of exposure in southern Florida [14]. By this metric, our testing simulated about 6 months of total exposure in southern Florida.

Figure 11. Barcode samples were initially UVA tested for 1000 h in a QUV accelerated weathering chamber.

Figure 12. Barcode samples installed in QUV accelerated weathering chamber at test conclusion. Samples are shown facing out but were turned inward toward UV lamps during testing.

QUV UVB TESTING (TEST 3)

Q-Lab staff installed 24 barcode samples into a QUV accelerated weathering chamber with UVB bulbs similar to the setup shown in Figure 11 and Figure 12. Testing followed a cycle like ASTM G154 Cycle 2. Samples were exposed to 4 h of light at 60°C black panel temperature followed by 4 h of condensation at 50°C black panel temperature. These cycles were repeated for a total of 500 h. Fluorescent UVB-313 bulbs at 310 nm were used with an irradiance of 0.71 W/(m^2 • nm) [13]. A comprehensive list of samples subjected to QUV UVB testing is included in Appendix C.

4.4 QUV AND Q-FOG TESTING (TEST 4)

Q-Lab's staff exposed 24 barcode samples to a 4 week sequence of alternating cycles of 1 week in a QUV accelerated weathering chamber followed by 1 week in a Q-FOG cyclic corrosion (salt fog) chamber. Testing followed ASTM D5894, "Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet)." In the QUV chamber, samples were set up similar to what is shown in Figure 11 and Figure 12. For 1 week (168 h), the samples were exposed to 4 h of light at 60°C black panel temperature followed by 4 h of condensation at 50°C black panel temperature. Fluorescent UVA-340 bulbs at 340 nm were used with an irradiance of 0.89 W/(m^2 • nm). At the end of 1 week, the samples were transferred to the salt fog chamber and set up as shown in Figure 13. The samples were exposed to 1 h of fog at ambient temperature then a 1 h dry off at 35°C. The fog solution was 0.05% sodium chloride and 0.35% ammonium sulfate [15]. After 1 week (168 h) in the salt fog chamber, the samples were transferred back to the QUV accelerated weathering chamber, and the cycle was repeated. A comprehensive list of samples subjected to QUV and Q-FOG testing is included in Appendix C.

Figure 13. Barcode samples were tested for 168 h in a Q-FOG cyclic corrosion (salt fog) chamber.

4.5 TEMPERATURE TESTING (TEST 5)

ORNL staff leased a Tenney TC20RC environmental enclosure from Thermal Product Solutions and had it installed at ORNL. ORNL staff then installed 61 barcode samples as shown in Figure 14. All samples affixed to coupons were hung vertically. A few stainless-steel samples (CERM, ETCH, YAGL) that were not affixed to such coupons were laid flat on the stainless wire racks with their markings facing up. Samples were exposed to −40°C for 7 days and then 113°C for 7 days. These cycles were repeated for a total of 6 weeks. Relative humidity was not controlled. The temperature ramp rate was not controlled such that the temperature changed as quickly as the chamber's heating and cooling capacity permitted. A comprehensive list of samples subjected to temperature testing is included in Appendix C.

Figure 14. Barcode samples were for 6 weeks in a Tenney TC20RC environmental enclosure.

4.6 CYCLIC CORROSION TESTING (TEST 6)

Staff at GTL installed 63 barcode samples into a salt fog chamber for cyclic corrosion testing. Samples were exposed to five cycles with each cycle consisting of the following steps:

1. *Ambient stage with stress*: 35 ± 3°C chamber temperature, 48 ± 3°C water temperature, approximately 95% relative humidity, and salt fog (0.9% sodium chloride) for 8 h

2. *Humid stage*: 49–60°C at approximately 95% relative humidity for 8 h

3. *Dry stage*: 60°C at less than 30% relative humidity for 8 h

One test cycle was equal to 24 h. This testing is similar to that described by GMW 14872, “GM Cyclic Corrosion Laboratory Test – Issue 4” [16]. Barcode samples were loaded into the salt fog chamber (Figure 15) for the ambient and humid stages and then transferred to a Tenney C30RC environmental test chamber for the dry stage (Figure 16). A comprehensive list of samples subjected to cyclic corrosion testing is included in Appendix C.

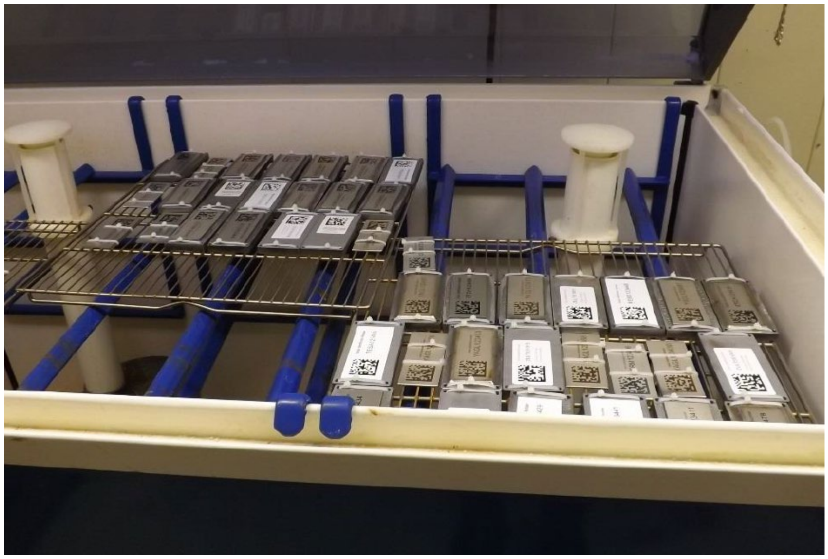


Figure 15. Barcode samples installed in GTL's salt fog chamber before ambient stage with stress exposure.

Figure 16. Barcode samples installed in GTL's environmental test chamber before dry stage exposure.

4.7 CORROSION TESTING (TEST 7)

Staff at GTL arranged 57 barcode samples in a salt fog chamber similar to the arrangement shown in Figure 15. Samples were exposed to a salt fog (0.9% sodium chloride) coupled with high temperature and high humidity for 200 h. This test followed the cycle described in ASTM B117, "Standard Practice for Operating Salt Spray (Fog) Apparatus" [17]. The salt fog chamber had a temperature of 35 ± 2°C, and the water temperature and relative humidity equalled 48 ± 3°C and 95%, respectively. A comprehensive list of samples subjected to corrosion testing is included in Appendix C.

4.8 BLOWING SAND/DUST TESTING (TEST 8)

Staff at GTL installed 57 barcode samples in a blowing sand/dust chamber (Figure 17). Testing followed MIL-STD 810G 510.6, "Sand and Dust 4.1 Procedure I – Blowing Dust," except temperature and humidity were not controlled [18]. Figure 18 shows how the dust was blown into the chamber. After testing, any dust that accumulated on the samples was brushed, wiped, or shaken off by methods that did not involve an air blast or vacuum cleaning. A comprehensive list of samples subjected to blowing sand/dust testing is included in Appendix C.

Figure 17. Barcode samples installed in GTL's sand/dust chamber before testing.

Figure 18. Introduction of test sand/dust into GTL's sand/dust chamber.

4.9 IMPACT TESTING (TEST 9)

Staff at GTL completed impact testing of 55 barcode samples. Testing followed IEC 61010-1, Section 8.2.2, "Impact Test" [19]. A smooth steel sphere with a mass of 500 g was placed 1,000 mm above the center of the barcode sample inside a guide tube (Figure 19). The removal of the pin (Figure 19, left) allowed the sphere to freely fall onto the sample for impact testing. Figure 20 shows the sphere on the

YAGL123469 barcode sample after the guide tube was removed postimpact testing. A comprehensive list of samples subjected to impact testing is included in Appendix C.

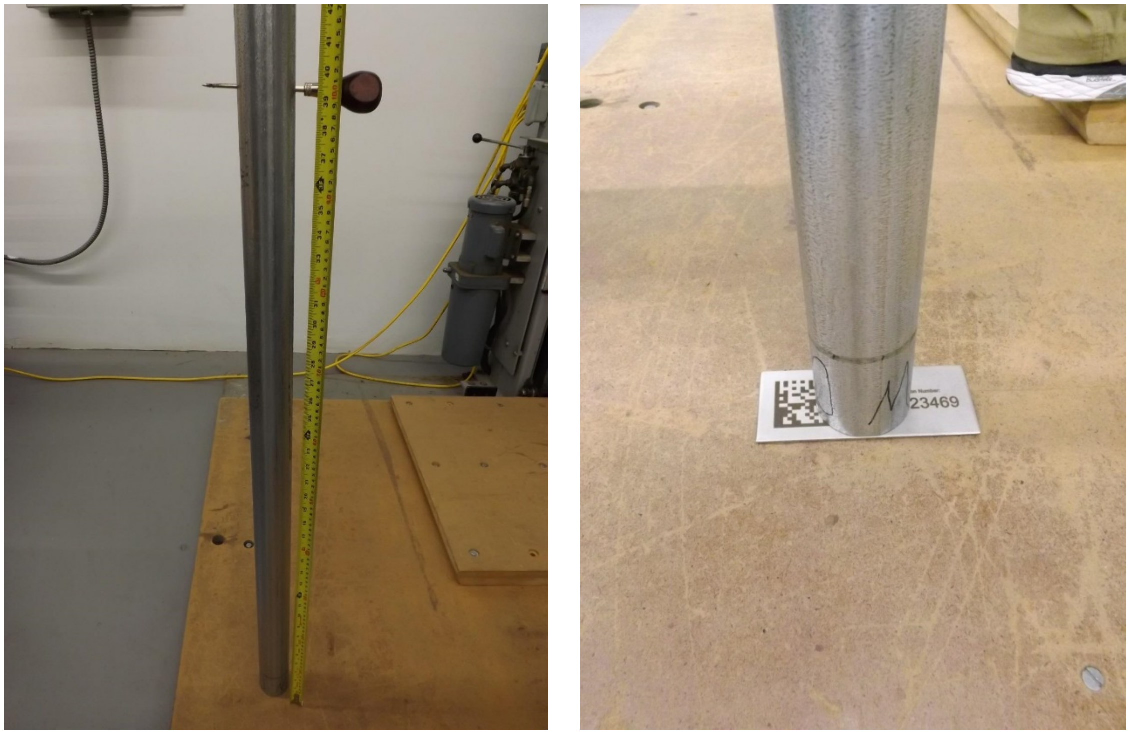


Figure 19. A 500 g smooth steel sphere is placed inside the guide tube 1,000 mm above the barcode sample surface. When the pin is removed, the sphere falls freely onto the sample for impact testing.

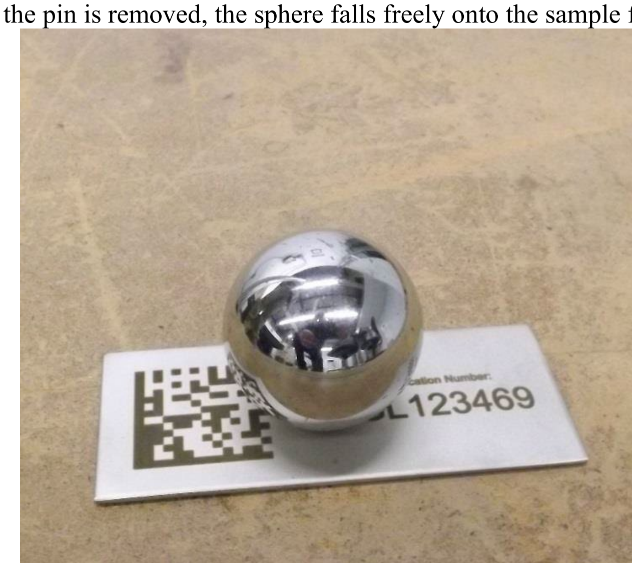


Figure 20. A 500 g smooth steel sphere on the YAGL123469 barcode sample after impact testing.

4.10 HIGH PRESSURE AND TEMPERATURE WATER JET TESTING (TEST 10)

Staff at GTL subjected 57 barcode samples to high-pressure and high-temperature water jet testing. Testing followed IEC 60529 CORR 1 - Degrees of Protection Provided by Enclosures (IP Code) - Edition 2.2, Test 14.2.9 “Test for second characteristic numeral 9 with a spray nozzle” [20]. The samples were attached to a grate using zip ties and then subsequently sprayed with a stream of water generated by a standard test nozzle (Figure 21). A comprehensive list of samples subjected to high pressure and temperature water jet is included in Appendix C.

Figure 21. Barcode samples subjected to high pressure and temperature water jet testing.

5. RESULTS BY ENVIRONMENTAL TEST

The ORNL team made both qualitative and quantitative assessments to evaluate the impact of the various environmental tests on the barcode samples. The test plan called for each batch of samples to be photographed and scanned using the barcode verifier before and after the environmental tests. Qualitative results were collected by comparing the photographs of the barcode samples before and after environmental exposure; quantitative results were collected by comparing the symbol contrast (ISO 15415) or cell contrast (ISO 29158) values from the barcode verifier scans before and after exposure. This Section provides the results from each of the ten environment tests.

5.1 Q-SUN XENON ARC LAMP TESTING (TEST 1)

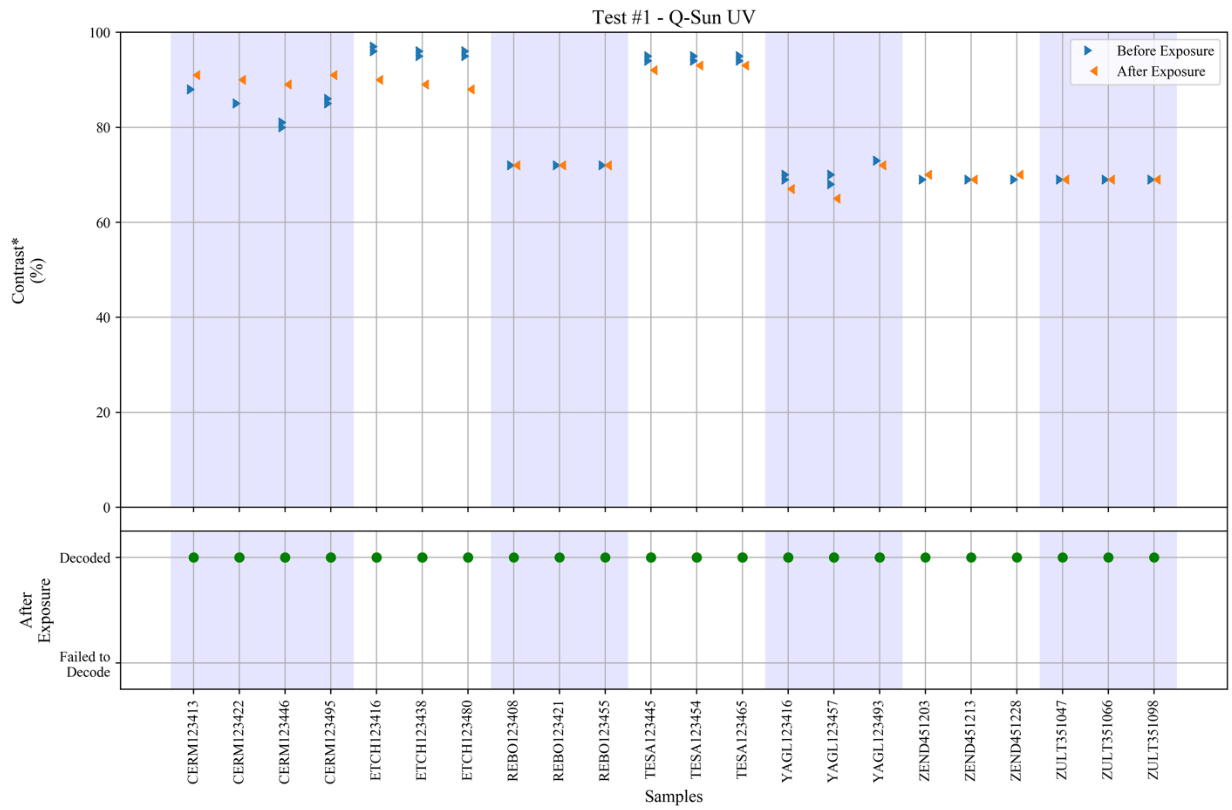
5.1.1 Qualitative

Figure 22 shows the 22 barcode samples before (left) and after (right) exposure to the Q-SUN xenon arc lamp testing. As shown in the figures, a mild discoloration is visible on the coupons after the exposure. Discoloration is also present on the stainless-steel samples (CERM, ETCH, and YAGL); however, most of the label-type barcode samples (REBO, TESA, ZEND, and ZULT) appeared unaffected. There does not appear to be any pattern to or correlation between the discoloration of a sample and its respective position within the test environment.

Figure 22. Barcode samples before (left) and after (right) Q-SUN xenon arc lamp testing.

5.1.2 Quantitative

After exposure, all 22 samples were successfully decoded with the barcode verifier. Figure 23 shows the cell or symbol contrast metric, depending on the appropriate standard, before and after exposure for samples subjected to Q-SUN xenon arc lamp testing. The ETCH stainless-steel samples showed the largest decrease in cell contrast compared to all other sample types; however, this decrease was not significant enough to prevent barcode decoding for any sample group.



** Cell contrast as measured by ISO 29158 for CERM, ETCH, YAGL, and TESA barcode samples.*
** Symbol contrast as measured by ISO 15415 for REBO, ZEND, and ZULT barcode samples.*

Figure 23. Cell or symbol contrast for barcode samples before and after Q-SUN xenon arc lamp testing.

5.2 QUV UVA TESTING (TEST 2)

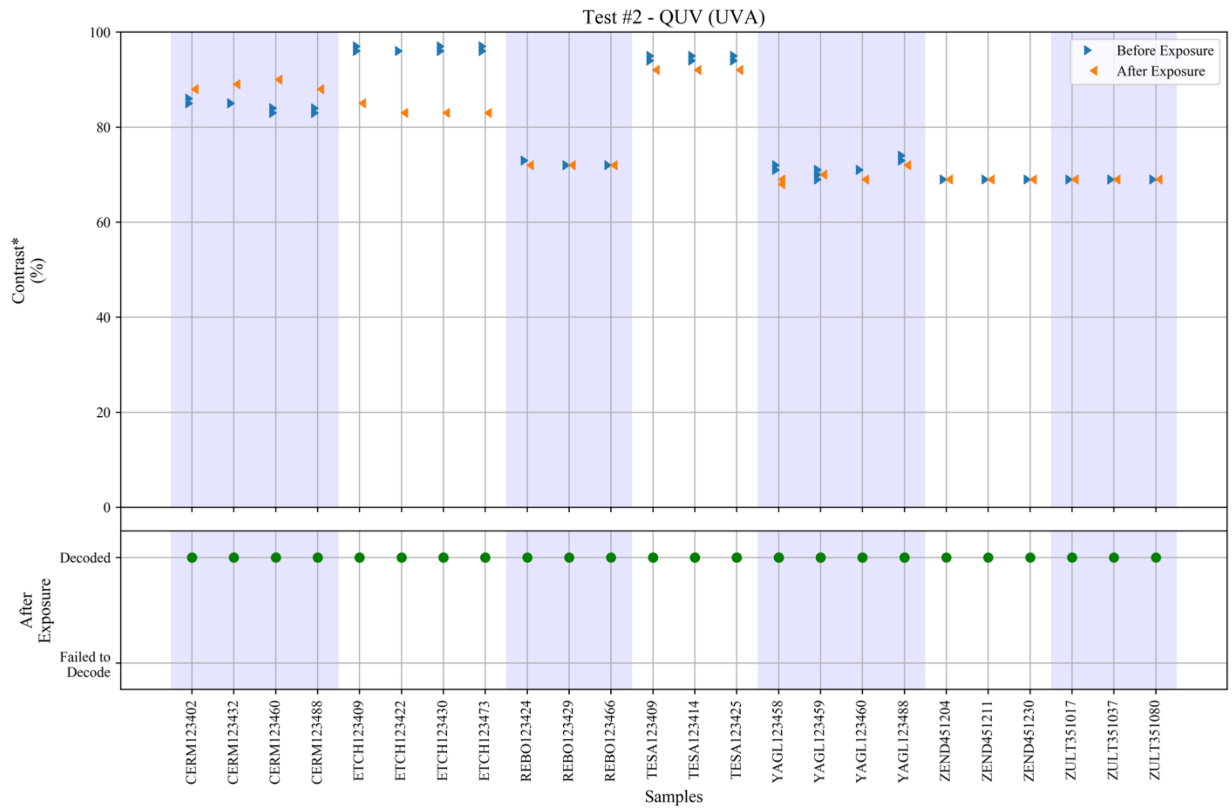
5.2.1 Qualitative

Figure 24 shows the 24 barcode samples before (left) and after (right) exposure to QUV UVA testing. The A516 coupons showed moderate signs of rust after exposure. The stainless-steel and label-type barcode samples themselves also appeared to have a rusty surface residue. It is believed that the A516 coupons rusted as a result of the condensation portion of the test cycle and moisture transported rust from the A516 coupon onto the barcode samples.

Figure 24. Barcode samples before (left) and after (right) QUV UVA testing.

5.2.2 Quantitative

After exposure, all 24 samples were successfully decoded with the barcode verifier. Figure 25 shows the cell or symbol contrast metric before and after exposure for samples subjected to UVA testing. Similar to Test 1, a majority of these samples showed little or no decrease in cell or symbol contrast from UVA exposure. The ETCH stainless-steel samples showed a larger decrease in cell contrast than the other sample types; however, this decrease was not significant enough to prevent barcode decoding for any sample group.



** Cell contrast as measured by ISO 29158 for CERM, ETCH, YAGL, and TESA barcode samples.*
** Symbol contrast as measured by ISO 15415 for REBO, ZEND, and ZULT barcode samples.*

Figure 25. Cell or symbol contrast for barcode samples before and after QUV UVA testing.

5.3 QUV UVB TESTING (TEST 3)

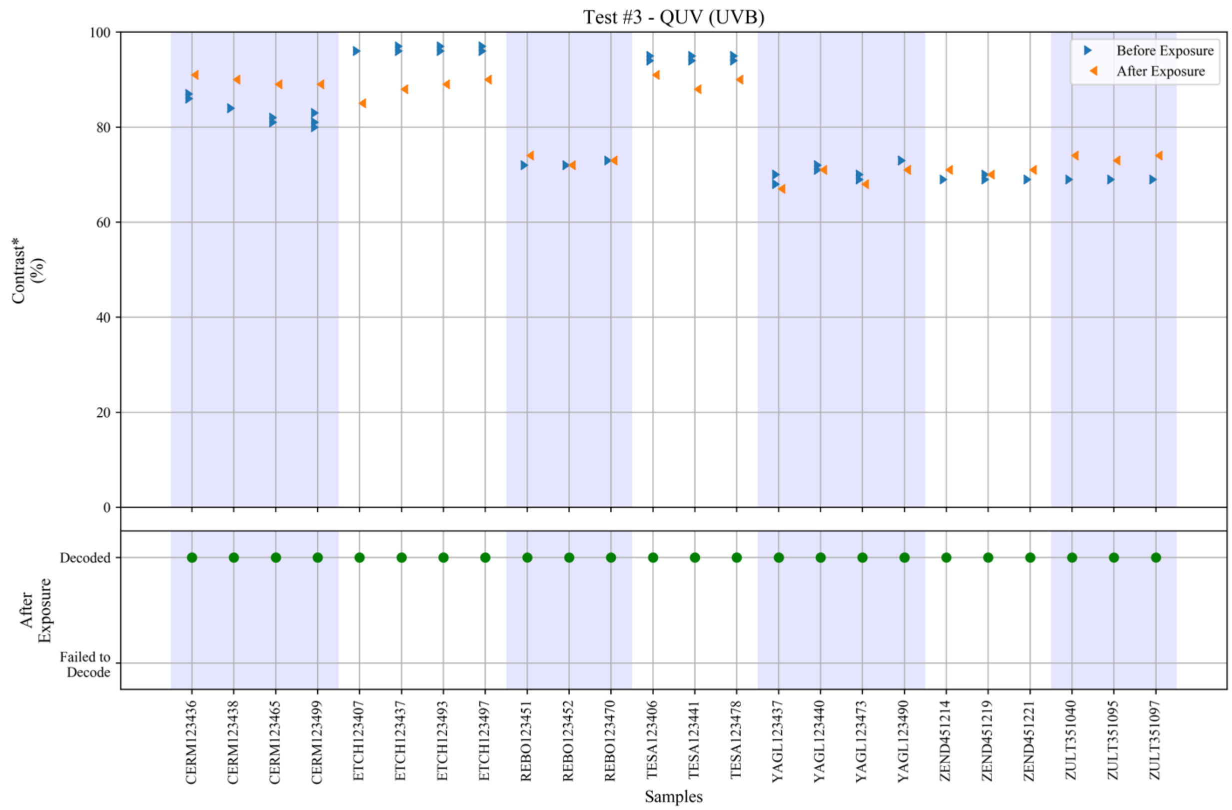
5.3.1 Qualitative

Figure 26 shows the 24 barcode samples before (left) and after (right) exposure to QUV UVB testing. The A516 coupons showed moderate signs of corrosion after exposure. The stainless-steel and label-type barcode samples themselves also appeared to have a rusty surface residue. We believe the A516 coupons rusted as a result of the condensation portion of the test cycle and moisture transported rust from the A516 coupon onto the barcode samples.

Figure 26. Barcode samples before (left) and after (right) UVB testing.

5.3.2 Quantitative

After exposure, all 24 samples were successfully decoded with the barcode verifier. Figure 27 shows the cell or symbol contrast metric before and after exposure for samples subjected to UVB testing. Similar to Test 1 and Test 2, a majority of these samples showed little or no degradation following this test. Consistent with other UV tests, the ETCH stainless-steel samples showed a larger decrease in cell contrast compared to the other barcode samples. Exposure from this test did not prevent barcode identification for any sample group.



** Cell contrast as measured by ISO 29158 for CERM, ETCH, YAGL, and TESA barcode samples.*
** Symbol contrast as measured by ISO 15415 for REBO, ZEND, and ZULT barcode samples.*

Figure 27. Cell or symbol contrast for barcode samples before and after QUV UVB testing.

5.4 QUV AND Q-FOG TESTING (TEST 4)

5.4.1 Qualitative

Figure 28 shows the 24 barcode samples before (left) and after (right) exposure to QUV and salt fog testing. The A516 coupons experienced significant rust. Many of the stainless-steel samples and especially the label-type samples also appeared to have a rusty surface residue.

Figure 28. Barcode samples before (left) and after (right) QUV and Q-FOG testing.

It is believed that the A516 coupons rusted as a result of the Q-FOG portion of the test cycle and moisture transported rust from the top down the front face of the samples. As shown in Figure 29, the specimens were installed in the Q-FOG machine with the barcode at the top. Figure 30, showing ZEND451202 with rust colored stains down the front face, is consistent with our hypothesis that moisture transported rust from the exposed A516 surface above the sample onto the sample surface. The label-type samples appear to have more rusty surface residue than the stainless-steel samples, which is likely because the thickness of the stainless-steel samples diverted moisture to the side and around the sample instead of over the front face of the thin label-type samples.

Figure 29. Barcode samples installed in Q-FOG cyclic corrosion (salt fog) chamber.

Figure 30. ZEND451202 with rust colored stains.

As described in the next section, one or more barcodes failed to decode after exposure. The authors suspected the barcodes were failing to decode because of an excessive amount of rusty residue on the samples. As a result each barcode sample was hand cleaned. Sample cleaning included a simple process with readily available supplies. Formula 409 cleaner was applied to each sample then wiped dry with a

Pig PR40 all-purpose wipe. The process was repeated with WD-40 solution. This cleaning process was not applied to the coupons. Figure 31 shows the samples after hand cleaning; all samples were then scanned again with the barcode verifier. The cleaning process was qualitatively very effective for all sample types except ZEND. As shown in Figure 32, the rusty residue seemed to permanently stain the ZEND labels.

Figure 31. Barcode samples subjected to QUV and Q-FOG testing after hand cleaning.

Figure 32. ZEND451202 before (left) and after (right) cleaning.

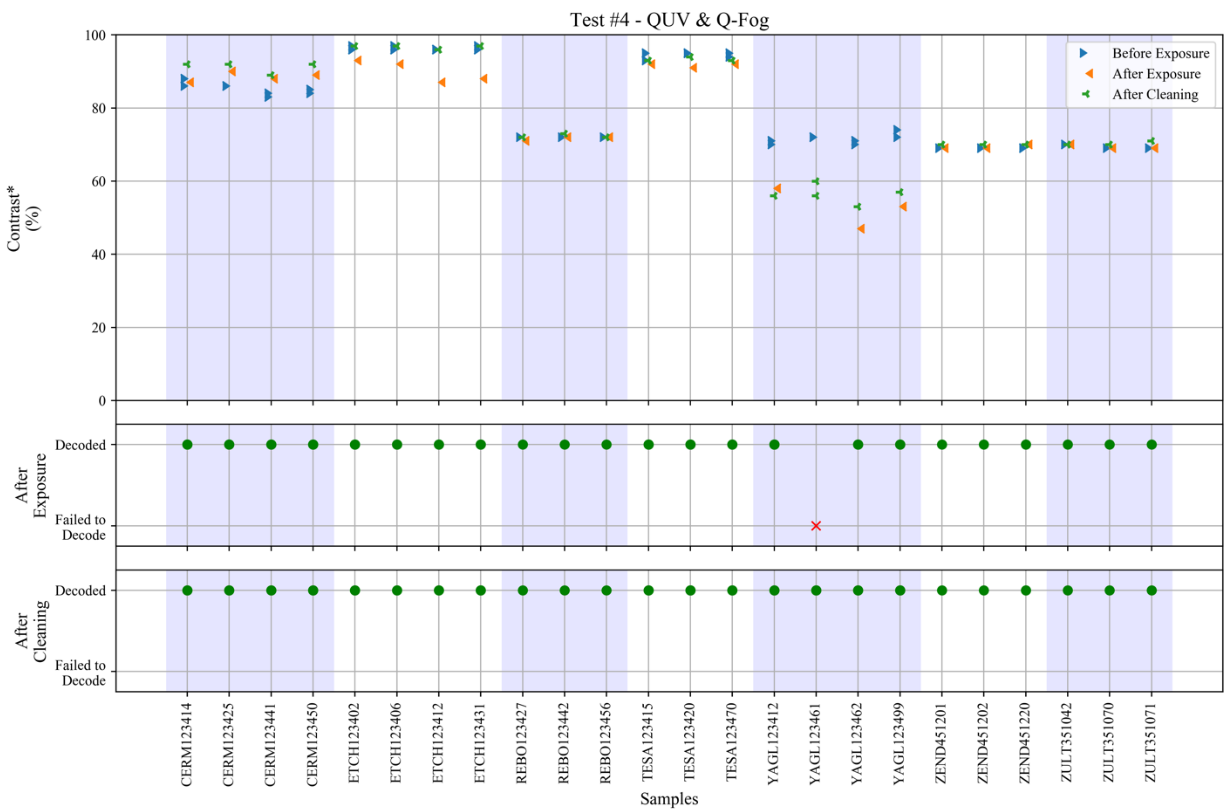
5.4.2 Quantitative

All samples were scanned after exposure. After exposure, 23 of the 24 samples were successfully decoded with the barcode verifier (YAGL123462 was not decoded). When compared with the rest of the tested samples, it is unclear why this sample did not initially decode. After the set of samples was hand cleaned with the method described above, all 24 samples successfully decoded, including YAGL123462. Figure 33 shows the cell or symbol contrast metric before exposure, after exposure, and after cleaning for samples subjected to UV and salt fog testing.

The contrast of the stainless-steel samples changed noticeably after exposure:

- CERM: contrast increased after exposure and increased slightly after cleaning
- ETCH: contrast decreased after exposure and increased back to pre-exposure level after cleaning
- YAGL: contrast decreased after exposure and tended to increase after cleaning

The label-type samples (REBO, TESA, ZEND, and ZULT) experienced little or no decrease in cell or symbol contrast as a result of exposure. Sample cleaning did not significantly change the contrast for the label-type samples.



** Cell contrast as measured by ISO 29158 for CERM, ETCH, YAGL, and TESA barcode samples.*
** Symbol contrast as measured by ISO 15415 for REBO, ZEND, and ZULT barcode samples.*

Figure 33. Before exposure, after exposure, and after cleaning cell or symbol contrast for barcode samples subjected to QUV and Q-FOG testing.

5.5 TEMPERATURE TESTING (TEST 5)

5.5.1 Qualitative

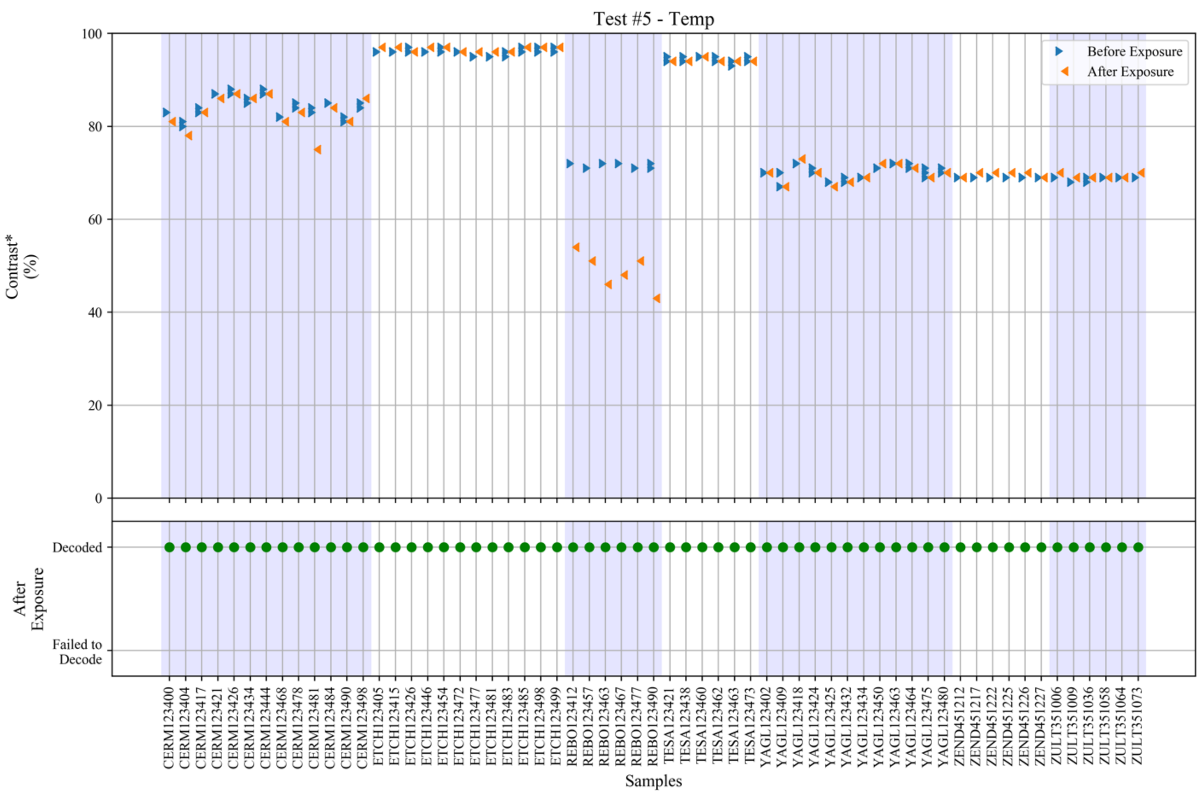
Figure 34 shows the 61 barcode samples before (top) and after (bottom) exposure to temperature testing. As shown in Figure 35, the REBO samples seemed to discolor as a result of exposure.

Figure 34. Barcode samples before (top) and after (bottom) temperature testing.

Figure 35. REBO123467 before (left) and after (right) temperature testing.

5.5.2 Quantitative

After exposure, all 61 samples were successfully decoded by the barcode verifier. Figure 36 shows the cell or symbol contrast metric before and after exposure for samples subjected to cyclic temperature testing. For the majority of the samples, a significant decrease in cell or symbol contrast did not occur as a result of exposure. However, the REBO samples showed a larger decrease in symbol contrast than the rest of the samples. As noted, this decrease did not preclude decoding by the barcode verifier.



** Cell contrast as measured by ISO 29158 for CERM, ETCH, YAGL, and TESA barcode samples.*
** Symbol contrast as measured by ISO 15415 for REBO, ZEND, and ZULT barcode samples.*

Figure 36. Cell or symbol contrast for barcode samples before and after temperature testing.

As described in the qualitative section above, the REBO sample set discolored as a result of this cyclic temperature exposure. It is not clear why this discoloration occurred. Because the sample background darkened from white to reddish-brown after exposure, the levels of contrast between dark and light elements of the barcode decreased, correlating to a significant decrease in measured symbol contrast.

5.6 CYCLIC CORROSION TESTING (TEST 6)

5.6.1 Qualitative

Figure 37 shows the 63 barcode samples before (top) and after (bottom) exposure to cyclic corrosion testing. As expected, the A516 coupons experienced significant rust as a result of the salt fog. A rusty residue is present on all coupons in a uniform pattern, regardless of sample type or how it was affixed. We believe rust was transported through the moist fog and deposited uniformly on the flat surface of the specimens as shown in Figure 38. As described in the next section, one or more barcodes failed to decode after exposure. The authors suspected the barcodes were failing to decode because of an excessive amount of rusty residue on the samples. As a result each barcode sample was hand cleaned and rescanned. Figure 39 shows the barcode samples after hand cleaning.

Figure 37. Barcode samples before (top) and after (bottom) cyclic corrosion testing.

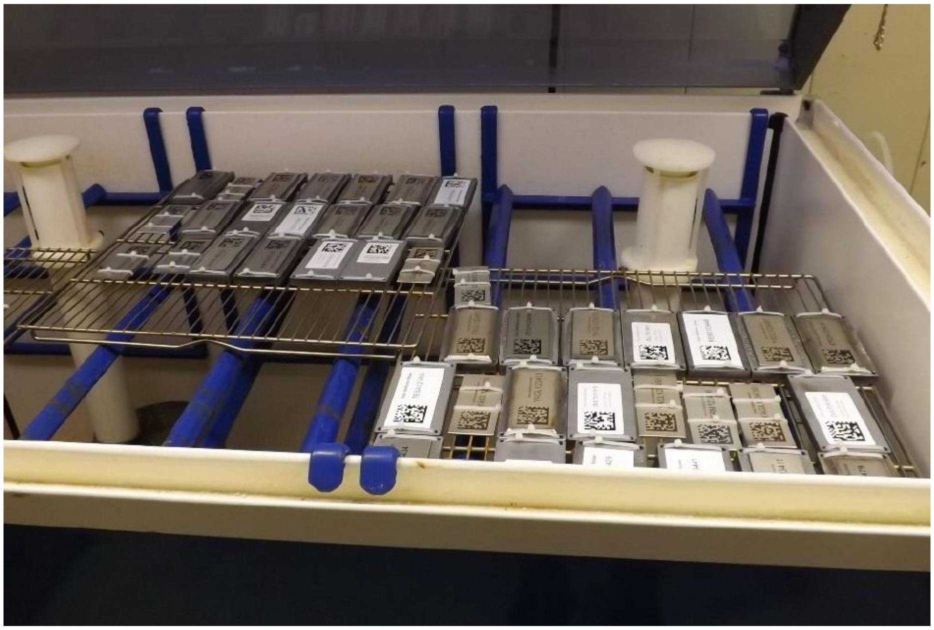


Figure 38. Barcode samples installed in GTL's salt fog chamber before ambient stage with stress exposure.

Figure 39. Barcode samples subjected to cyclic corrosion testing after hand cleaning.

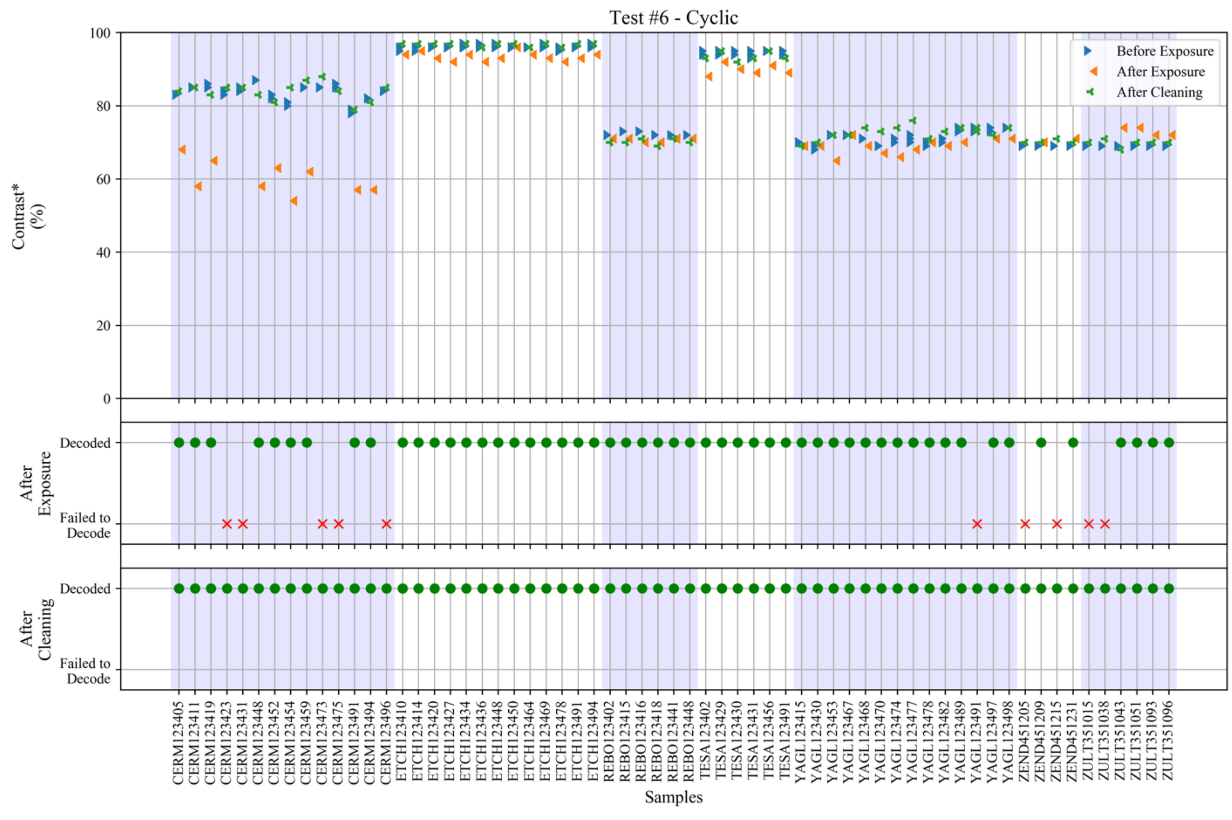
5.6.2 Quantitative

After exposure, 53 samples successfully decoded, but 10 samples failed to decode.

- 6 stainless-steel samples failed to decode.
  - 5 CERM
  - 1 YAGL

- 4 label-type samples failed to decode.
  - 2 ZEND
  - 2 ZULT

Because one or more barcodes failed to decode after exposure, the rusty residue on the samples was cleaned as described in Section 5.4.1, and each sample was scanned again. After cleaning, the barcode verifier successfully decoded all 63 samples. Figure 39 shows each sample after cleaning. Figure 40 shows the cell or symbol contrast metric before exposure, after exposure, and after cleaning for samples subjected to cyclic corrosion testing.



** Cell contrast as measured by ISO 29158 for CERM, ETCH, YAGL, and TESA barcode samples.*
** Symbol contrast as measured by ISO 15415 for REBO, ZEND, and ZULT barcode samples.*

Figure 40. Before exposure, after exposure, and after cleaning cell or symbol contrast for barcode samples subjected to cyclic corrosion testing.

The CERM, ETCH, YAGL, and TESA sample sets all had a noticeable decrease in cell contrast after exposure and before cleaning, while the symbol contrast of REBO, ZEND, and ZULT sample sets did not significantly decrease. However, after the samples were cleaned, the barcode verifier measure little to no cell or symbol contrast degradation for each sample.

5.7 CORROSION TESTING (TEST 7)

5.7.1 Qualitative

Figure 41 shows the 57 barcode samples before (top) and after (bottom) exposure to corrosion (salt fog) testing. As shown, the A516 coupons rusted considerably. Rusty residue was present on all samples, regardless of sample type or attachment method.

Figure 41. Barcode samples before (top) and after (bottom) corrosion testing.

Because of the heavy amount of rust present on the samples, each barcode sample was hand cleaned as described in Section 5.4.1. Figure 42 shows each sample after cleaning; all samples were then scanned again with the barcode verifier.

Figure 42. Barcode samples subjected to corrosion testing after cleaning.

5.7.2 Quantitative

After exposure, 30 of the 57 samples failed to decode with the barcode verifier. 22 stainless-steel samples failed to decode.

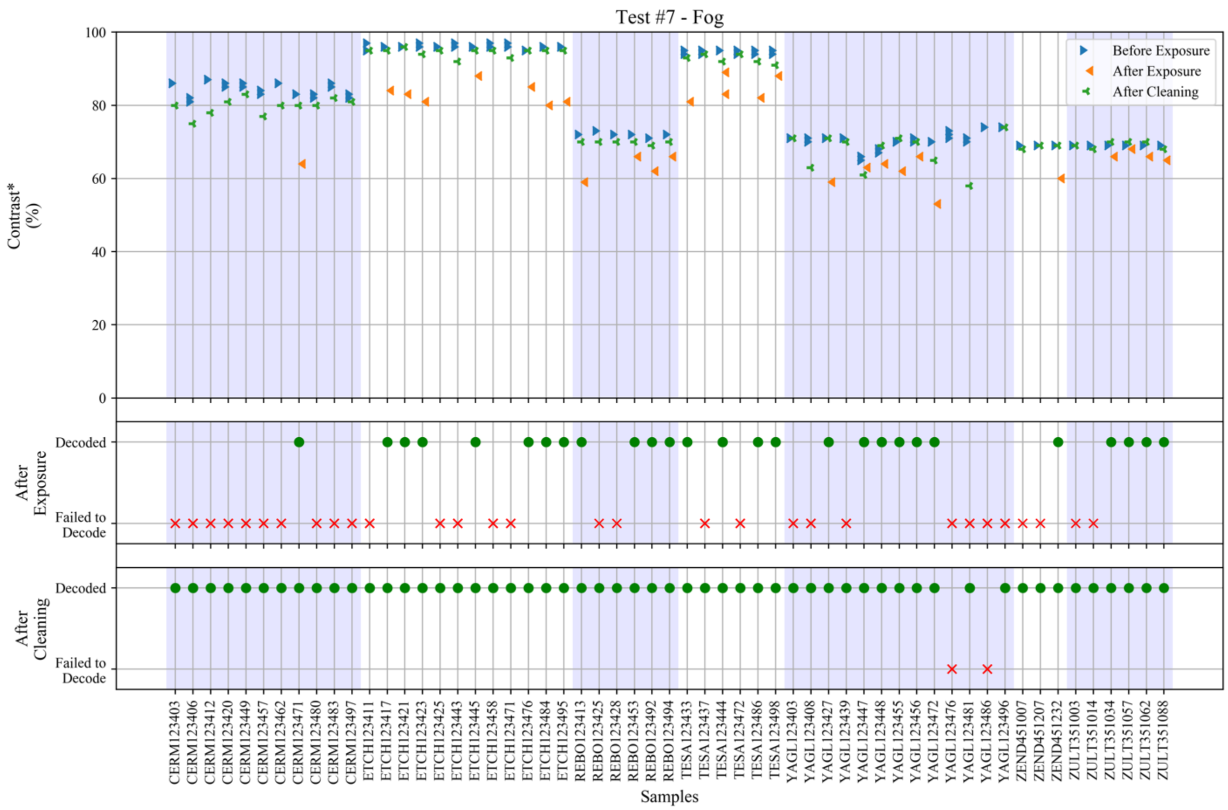
- 10 CERM
- 5 ETCH
- 7 YAGL

- 8 label-type samples failed to decode.
  - 2 REBO
  - 2 TESA
  - 2 ZEND
  - 2 ZULT

After exposure, but before cleaning, the samples that were decoded showed a decrease in cell or symbol contrast. The 14 CERM, ETCH, and YAGL samples that the barcode verifier decoded demonstrated the largest decrease in cell contrast after testing before cleaning when compared to the other sample types. We believe the ball-blasted finish of stainless steel left a porous surface for the rust residue to adhere to and impacted contrast for these sample types.

After cleaning, two YAGL samples did not decode: YAGL123476 and YAGL123486. Figure 43 shows the cell or symbol contrast metric before exposure, after exposure, and after cleaning for samples subjected to corrosion testing.

After the samples were hand cleaned, 55 of the 57 samples showed a significantly smaller decrease in cell or symbol contrast compared to their before-exposure values. It is not immediately clear why YAGL123476 and YAGL123486 did not decode after hand cleaning.



** Cell contrast as measured by ISO 29158 for CERM, ETCH, YAGL, and TESA barcode samples.*
** Symbol contrast as measured by ISO 15415 for REBO, ZEND, and ZULT barcode samples.*

Figure 43. Before exposure, after exposure, and after cleaning cell or symbol contrast for barcode samples subjected to corrosion testing.

5.8 BLOWING SAND/DUST TESTING (TEST 8)

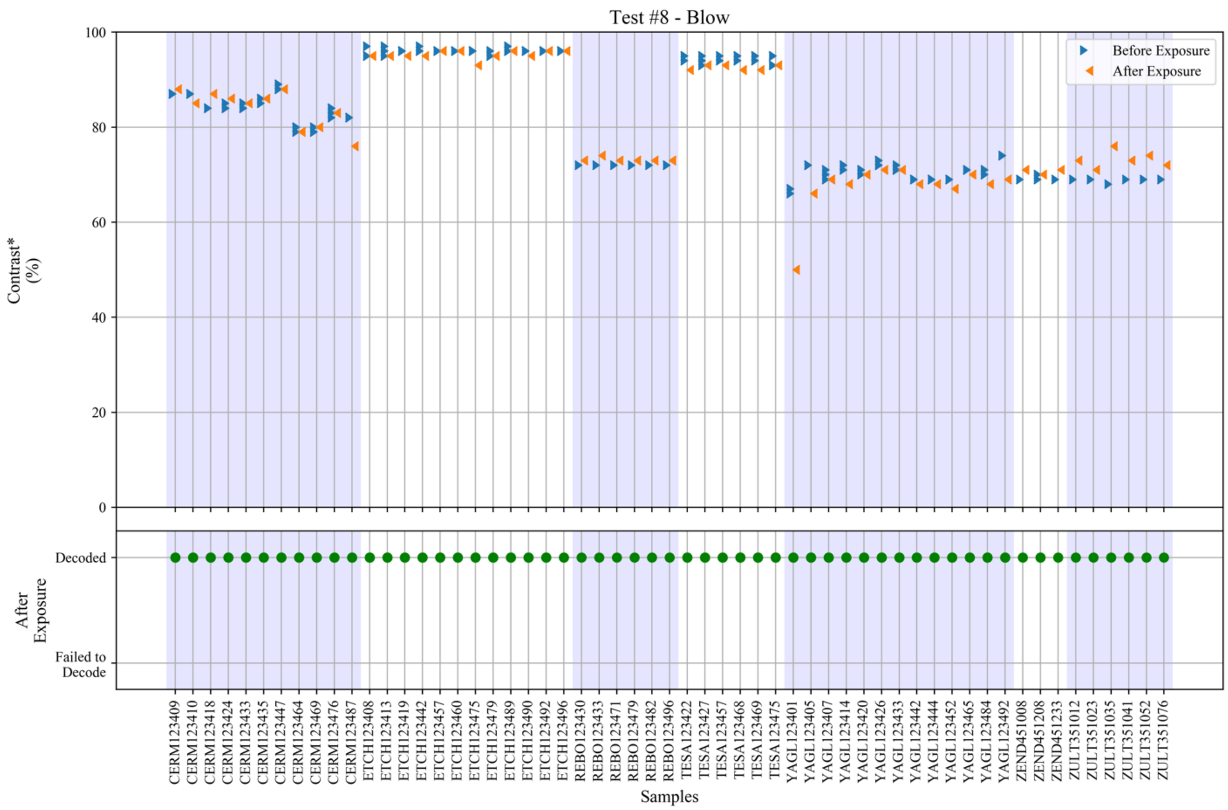
5.8.1 Qualitative

Figure 44 shows the 57 barcode samples before (top) and after (bottom) exposure to blowing sand and dust testing. The A516 coupons (mainly the polished coupons) show mild signs of oxidation. Any oxidation patterns did not have a significant effect on the barcode decoding.

Figure 44. Barcode samples before (top) and after (bottom) blowing sand/dust testing.

5.8.2 Quantitative

After exposure, all 57 samples were successfully decoded by the barcode verifier. Figure 45 shows the cell or symbol contrast metric before and after exposure for samples subjected to blowing sand and dust testing. A significant decrease in cell or symbol contrast did not occur as a result of testing. The decrease in cell or symbol contrast was minimal for label-type samples (REBO, TESA, ZEND, ZULT), and almost no decrease in cell contrast was measured for stainless-steel samples (CERM, ETCH, YAGL). One noted outlier was the YAGL123401 sample, which demonstrated a sizable decrease in cell contrast after exposure. It is not clear why this decrease occurred.



** Cell contrast as measured by ISO 29158 for CERM, ETCH, YAGL, and TESA barcode samples.*
** Symbol contrast as measured by ISO 15415 for REBO, ZEND, and ZULT barcode samples.*

Figure 45. Cell or symbol contrast for barcode samples before and after blowing sand/dust testing.

5.9 IMPACT TESTING (TEST 9)

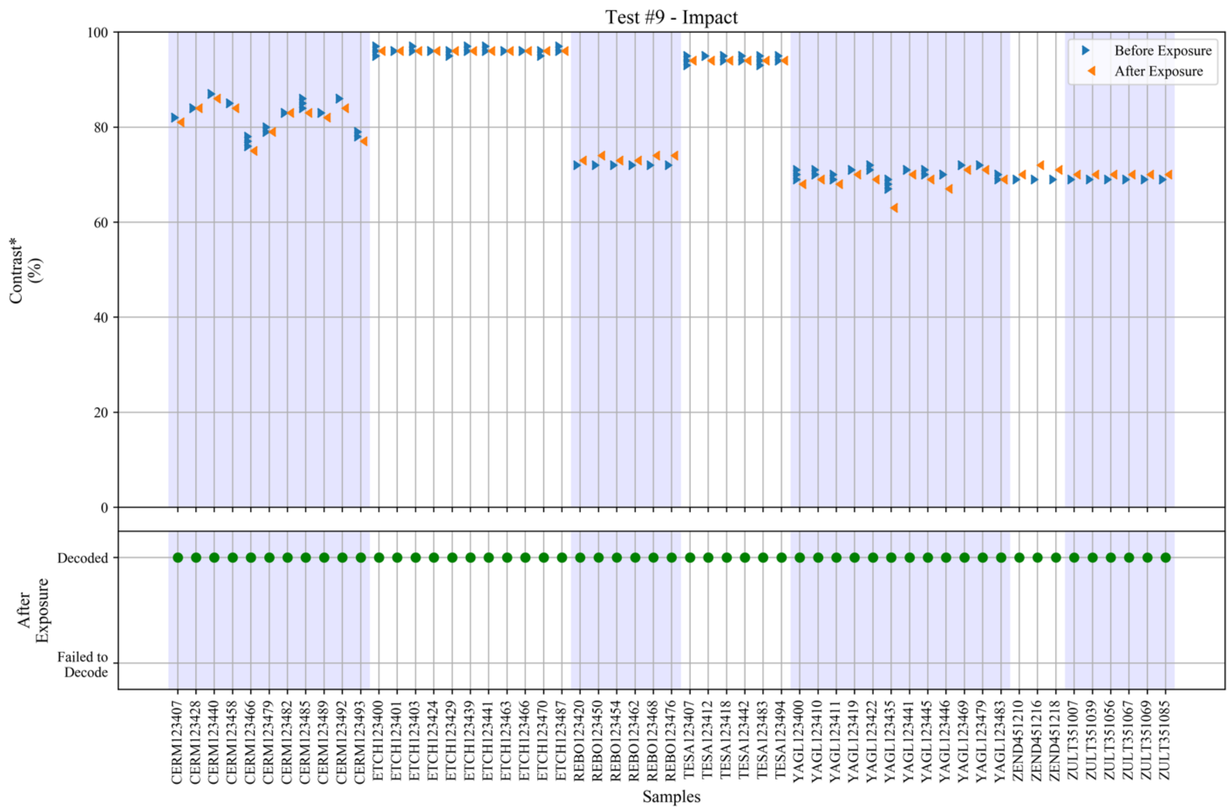
5.9.1 Qualitative

Figure 46 shows the 55 barcode samples before (top) and after (bottom) after exposure to impact testing. Similar to the samples in Test 8, the A516 coupons (mainly the polished coupons) showed mild signs of oxidation. Any oxidation patterns did not have a significant effect on the barcode decoding.

Figure 46. Barcode samples before (top) and after (bottom) impact testing.

5.9.2 Quantitative

After exposure, all 55 samples were successfully decoded with the barcode verifier. Figure 47 shows the cell or symbol contrast metric before and after exposure for samples subjected to impact testing. A significant decrease in cell or symbol contrast did not occur as a result of testing. There was a slightly larger decrease in cell contrast for the YAGL samples compared to all others; however, the decrease was not significant.



** Cell contrast as measured by ISO 29158 for CERM, ETCH, YAGL, and TESA barcode samples.*
** Symbol contrast as measured by ISO 15415 for REBO, ZEND, and ZULT barcode samples.*

Figure 47. Cell or symbol contrast for barcode samples before and after impact testing.

5.10 HIGH PRESSURE AND TEMPERATURE WATER JET (TEST 10)

5.10.1 Qualitative

Figure 48 shows the 57 barcode samples before (top) and after (bottom) exposure to high pressure and temperature water jet testing. The A516 coupons show moderate signs of oxidation. These oxidation patterns are predominantly surface rust patterns, likely attributed to the rust from the introduction of moisture during testing. This did not have significant effect on the sample scans.

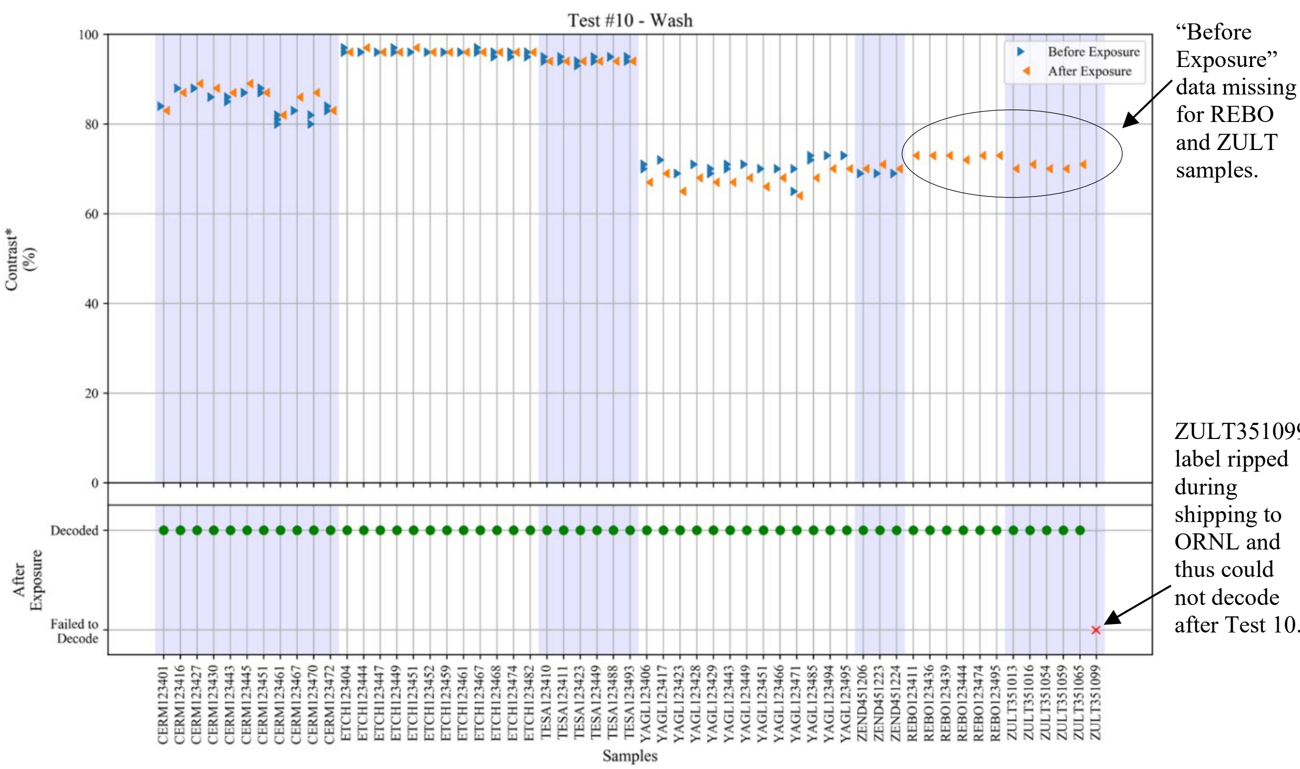
Figure 48. Barcode samples before (top) and after (bottom) high pressure and temperature water jet testing.

5.10.2 Quantitative

After exposure, 54 of the 55 samples were successfully decoded with the barcode verifier. Based on visual inspection, we determined that ZULT351099 had ripped at some point between the pre-exposure scan and the postexposure scan. Figure 49 shows ZULT351099 with the rip circled in red.

Figure 49. ZULT351099 shown with ripped barcode circled in red.

Figure 50 shows the cell or symbol contrast metric before and after exposure for samples subjected to high-pressure and temperature water jet testing. The cell contrast did not significantly change for the CERM, ETCH, TESA, or ZEND samples. The contrast decreased slightly for the YAGL samples. The team failed to scan the REBO and ZULT samples before they were shipped, so the before-exposure data is not shown in Figure 50.



** Cell contrast as measured by ISO 29158 for CERM, ETCH, YAGL, and TESA barcode samples.*
** Symbol contrast as measured by ISO 15415 for REBO, ZEND, and ZULT barcode samples.*

Figure 50. Cell or symbol contrast for barcode samples before and after high pressure and temperature water jet testing.

5.11 SUMMARY OF RESULTS BY TEST

After cleaning samples from some of the tests, the temperature testing had the largest effect on the contrast of the samples on average, and the cyclic tests had the smallest effect (Table 4).

Table 4. Summary of cell or symbol contrast values for each test before exposure, after exposure, and after cleaning (sorted by change in contrast).

Test	Before Exposure	After Exposure	After Cleaning	Difference After Exposure	Difference After Cleaning	Final Difference
5 – Temp	79.58	75.91	—	(3.67)	—	(3.67)
7 – Fog	79.84	68.87	77.46	(10.97)	(2.38)	(2.38)
2 - QUV (UVA)	80.03	77.73	—	(2.30)	—	(2.30)
10 - Wash	81.70	79.63	—	(2.07)	—	(2.07)
4 - QUV & Q-FOG	80.18	76.17	78.57	(4.01)	(1.61)	(1.61)
1 - Q-Sun UV	79.83	78.65	—	(1.18)	—	(1.18)
3 - QUV (UVB)	79.77	79.14	—	(0.63)	—	(0.63)
8 - Blow	79.75	79.42	—	(0.33)	—	(0.33)
9 - Impact	79.49	79.26	—	(0.24)	—	(0.24)
6 - Cyclic	79.82	75.23	79.59	(4.59)	(0.23)	(0.23)

RESULTS BY BARCODE SAMPLE TYPE

This section describes the overall performance of each of the 7 types of samples to the 10 environmental tests that were performed.

5.12 CERM STAINLESS-STEEL SAMPLES

Figure 51 shows the cell contrast metric for the 87 CERM samples evaluated before and after each environmental test. As shown in the previous sections for tests with corrosion, Tests 4, 6, and 7 also include data points for cell contrast before and after sample cleaning. The samples subjected to the remaining tests (Tests 1, 2, 3, 5, 8, 9, and 10) were not hand cleaned and rescanned.

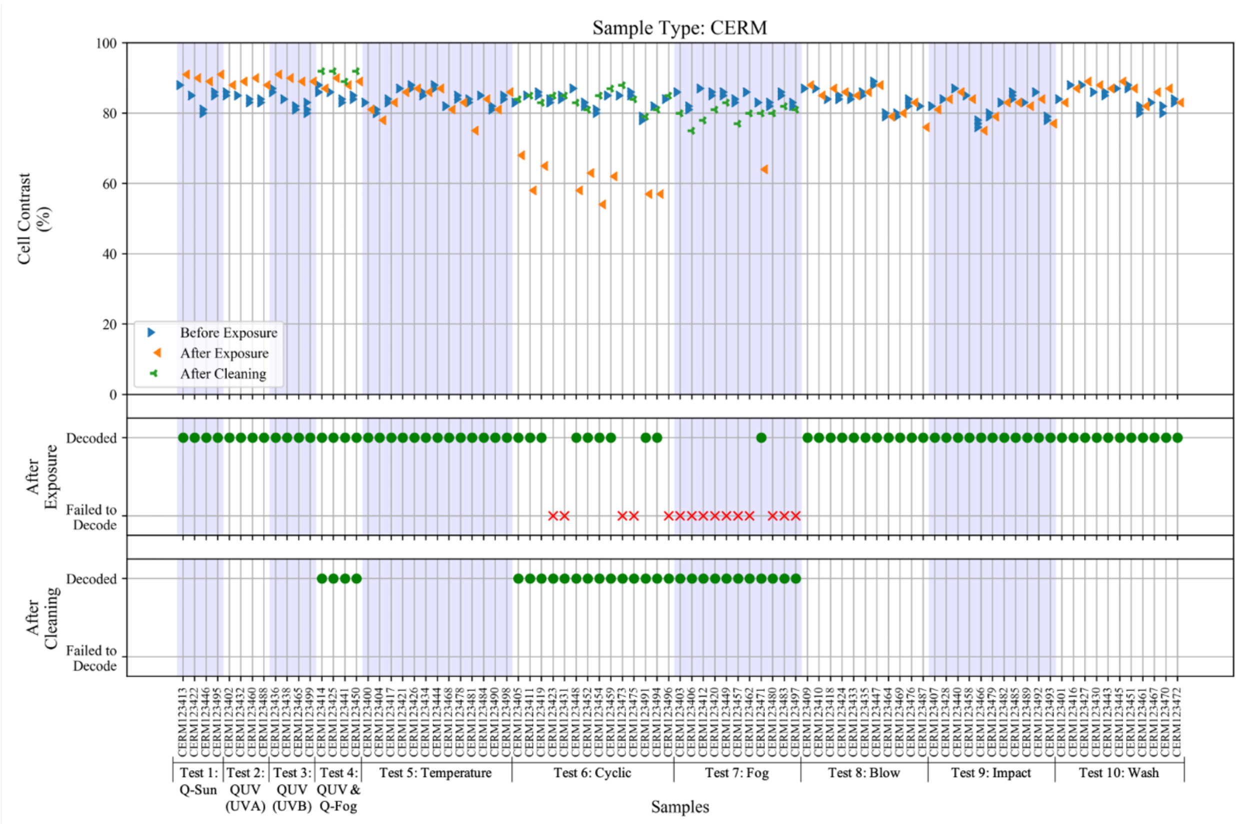


Figure 51. Cell contrast for CerMark-coated laser-marked stainless-steel (CERM) barcode samples before and after all environmental tests.

The CERM samples were significantly affected by the corrosion-based environmental tests. The CERM samples performed the worst when exposed to salt fog (Test 7), with only 1 of the 11 samples decoding before hand cleaning. For the samples that decoded across all tests, the after-exposure cell contrast decrease was largest after cyclic testing (Test 6), which was likely caused by the presence of rust on the barcodes. After the samples subjected to Tests 4, 6, and 7 were hand cleaned, all barcodes in Tests 6 and 7 decoded, and the samples subjected to Test 6 showed little to no change in cell contrast. Test 7 samples showed the highest decrease in cell contrast, but the after-exposure values are still within 10% of the before-exposure values for all samples. Note, all 87 CERM sample identification numbers could be manually read by an ORNL researcher both before and after hand cleaning, regardless of the sample's ability to decode.

5.13 ETCH STAINLESS-STEEL SAMPLES

Figure 52 shows the cell contrast metric for the 87 ETCH samples evaluated before and after each environmental test. As shown in the previous sections for tests with corrosion, Tests 4, 6, and 7 also include data points for cell contrast before and after sample cleaning. The samples subjected to the remaining tests (Tests 1, 2, 3, 5, 8, 9, and 10) were not hand cleaned and rescanned.

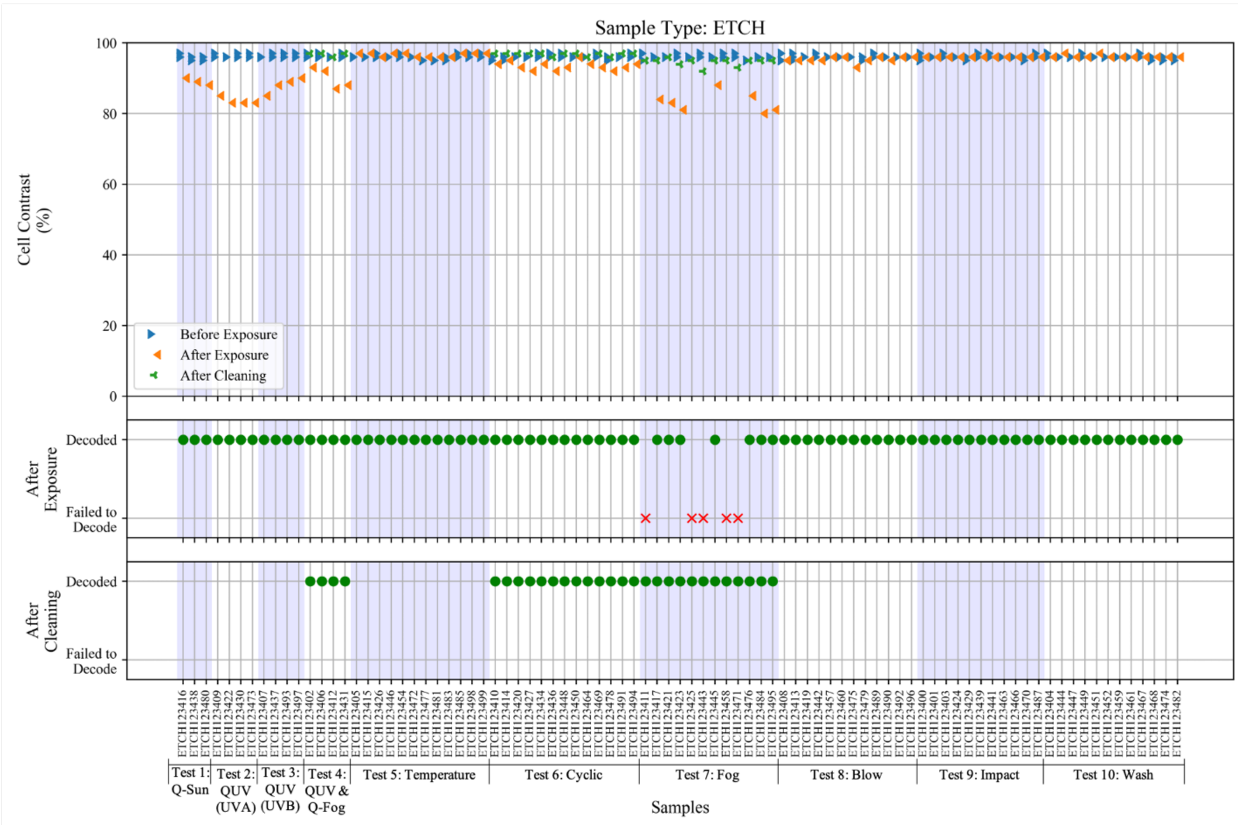


Figure 52. Cell contrast for chemically etched stainless-steel (ETCH) barcode samples before and after all environmental tests.

When compared across all test types, the ETCH samples show a susceptibility to UV degradation, with the largest decreases in cell contrast seen after UVA exposure during Test 2. Corrosion-based tests also caused a significant decrease in cell contrast, which was visible for the samples exposed to Tests 6 and 7. Five of the twelve samples exposed to Test 7 did not decode after environmental exposure. After hand cleaning, all 12 samples exposed to Test 7 successfully decoded, and a significant change in the cell contrast was not attributable to the corrosion of the barcode. Thus, it can be assumed that the rust dust present on the coupons before hand cleaning was the source of cell contrast decrease. Note, all 87 ETCH sample identification numbers could be manually read by an ORNL researcher both before and after hand cleaning, regardless of the sample's ability to decode.

5.14 YAGL STAINLESS-STEEL SAMPLES

Figure 53 shows the cell contrast metric for the 92 YAGL samples evaluated before and after each environmental test. As shown in the previous sections for tests with corrosion, Tests 4, 6, and 7 also include data points for cell contrast before and after sample cleaning. The samples subjected to the remaining tests (Tests 1, 2, 3, 5, 8, 9, and 10) were not hand cleaned and rescanned.

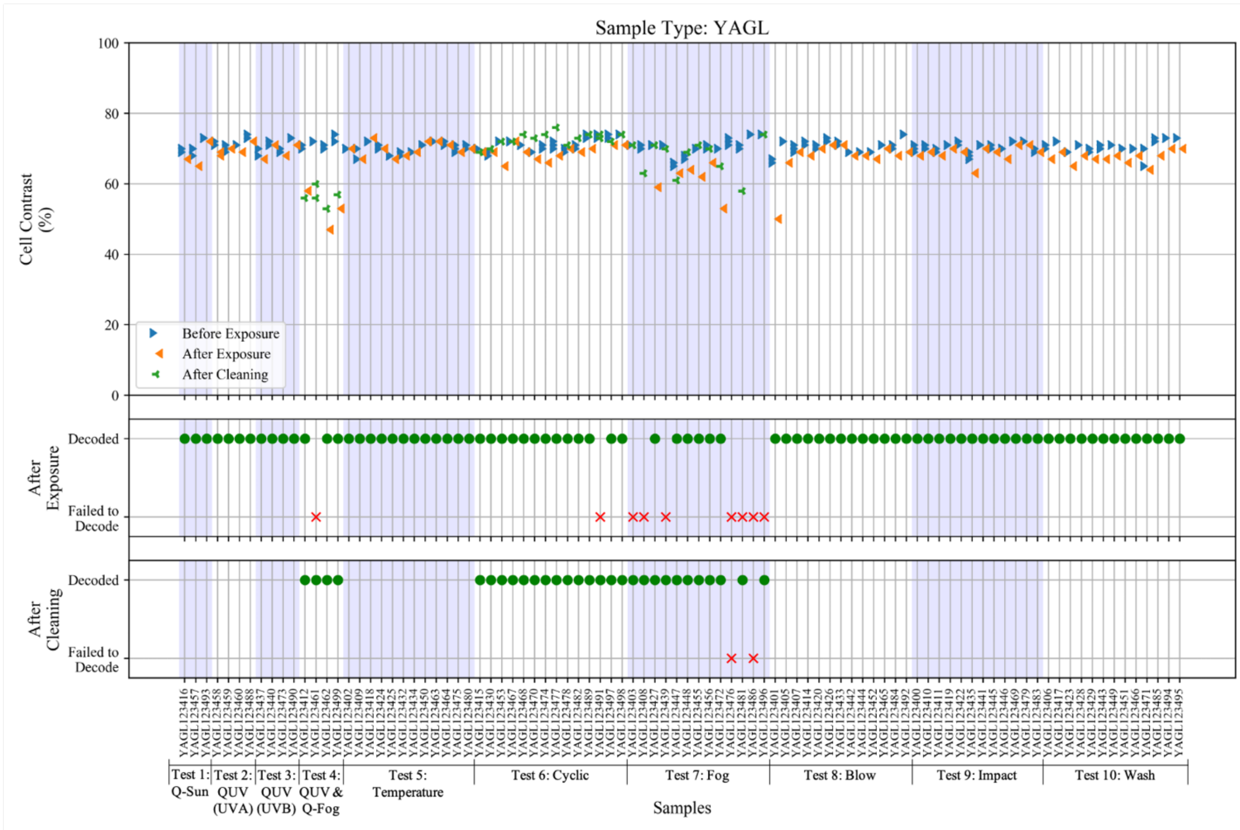


Figure 53. Cell contrast for laser-marked stainless-steel (YAGL) barcode samples before and after all environmental tests.

Overall, the YAGL samples have a lower before-exposure cell contrast than other stainless-steel samples (CERM and ETCH). The YAGL samples appear very succeptable to the combination of UV and salt fog exposure as demonstrated in Test 4. YAGL samples subjected to Test 7 were the only samples that could not be decoded after being hand cleaned (e.g., YAGL123476 and YAGL123486). Note, all 92 YAGL sample identification numbers could be manually read by an ORNL researcher both before and after hand cleaning, regardless of the sample's ability to decode.

5.15 REBO LABEL-TYPE SAMPLES

Figure 54 shows the symbol contrast metric for the 48 REBO samples evaluated before and after each environmental test. As shown in the previous sections for tests with corrosion, Tests 4, 6, and 7 also include data points for symbol contrast before and after sample cleaning. The samples subjected to the remaining tests (Tests 1, 2, 3, 5, 8, 9, and 10) were not hand cleaned and rescanned.

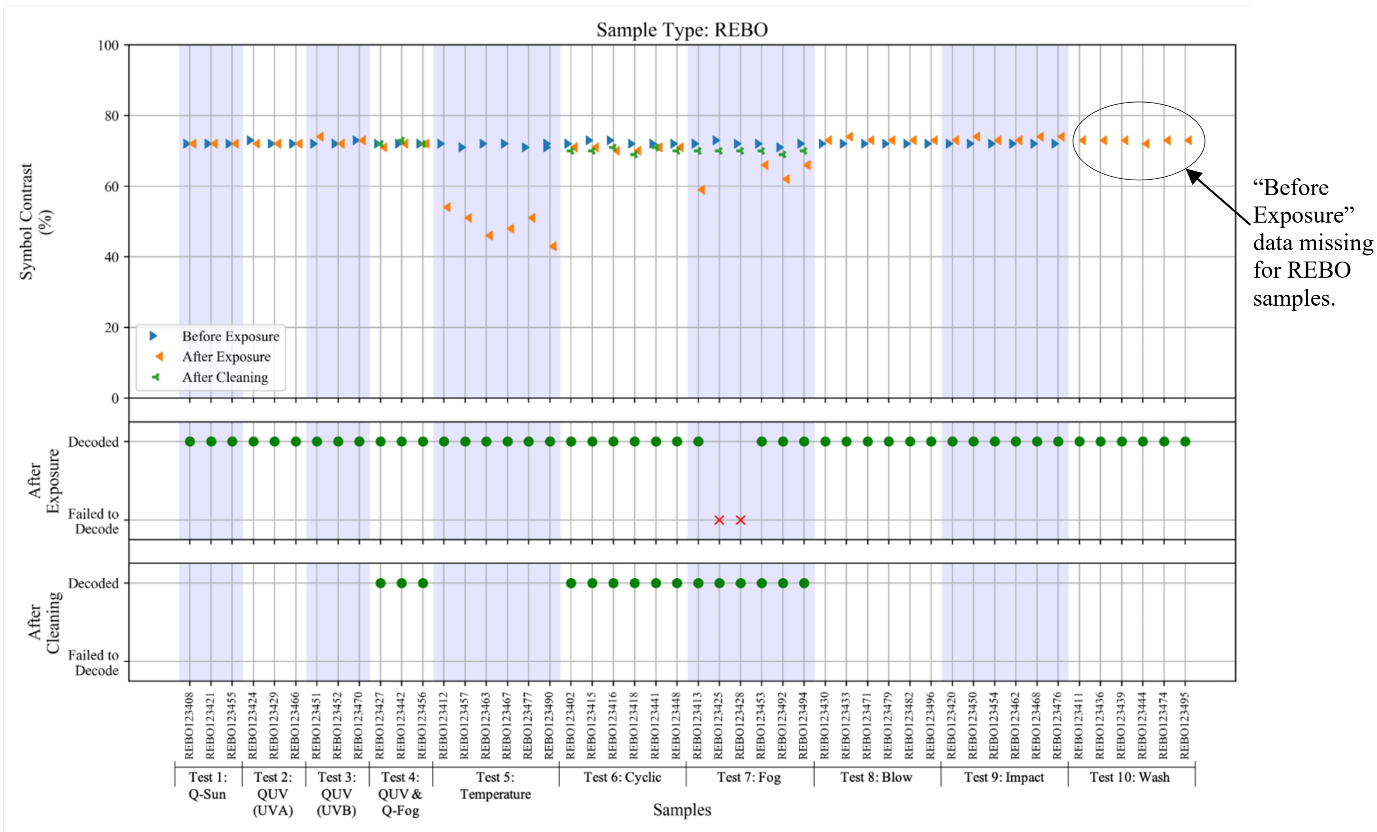


Figure 54. Symbol contrast for Rebo premium vinyl label (REBO) barcode samples before and after all environmental tests.

The REBO sample set was relatively consistent across all environmental tests, with the exception of temperature exposure. For the temperature variation tests (Test 5), the REBO samples performed the worst of any sample set. As shown in Figure 23, the samples discolored as a result of the testing. This caused a significant decrease in the symbol contrast compared to all other tests, showing a distinct weakness for this sample type. For corrosion tests, the performance of the REBO samples was comparable to other label-type barcode samples (TESA, ZEND, ZULT), showing little to no symbol contrast decrease after sample cleaning.

The team failed to locate before-exposure scans for Test 10. Since the before-exposure cell contrast values are consistent across all the other tests, the authors suggest that the before-exposure symbol contrast values for the pressure and temperature water jet test were similar to the before-exposure values of REBO samples for the other tests.

Note, all 48 REBO sample identification numbers could be manually read by an ORNL researcher both before and after hand cleaning, regardless of the sample's ability to decode.

5.16 TESA LABEL-TYPE SAMPLES

Figure 55 shows the cell contrast metric for the 48 TESA samples evaluated before and after each environmental test. As shown in the previous sections for tests with corrosion, Tests 4, 6, and 7 also include data points for cell contrast before and after sample cleaning. The samples subjected to the remaining tests (Tests 1, 2, 3, 5, 8, 9, and 10) were not hand cleaned and rescanned.

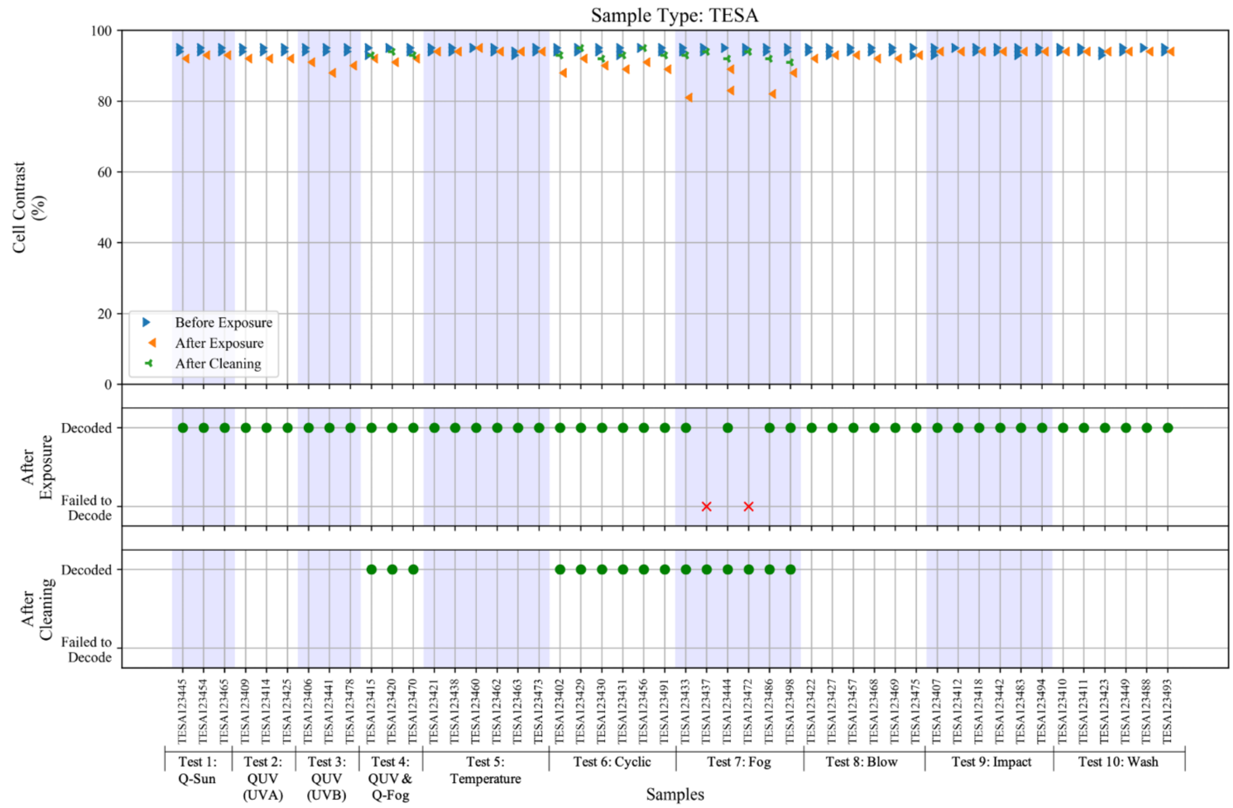


Figure 55. Cell contrast for laser-marked Tesa tape (TESA) barcode samples before and after all environmental tests.

The TESA sample set was one of the most consistent sample types. UVB exposure (Test 3) seemed to have the greatest influence on cell contrast. This was followed by salt fog exposure (Test 7), after which two of the six samples failed to decode. Note, all 48 TESA sample identification numbers could be manually read by an ORNL researcher both before and after hand cleaning, regardless of the sample's ability to decode.

5.17 ZEND LABEL-TYPE SAMPLES

Figure 56 shows the symbol contrast metric for the 34 ZEND samples evaluated before and after each environmental test. As shown in the previous sections for tests with corrosion, Tests 4, 6, and 7 also include data points for symbol contrast before and after sample cleaning. The samples subjected to the remaining tests (Tests 1, 2, 3, 5, 8, 9, and 10) were not hand cleaned and rescanned.

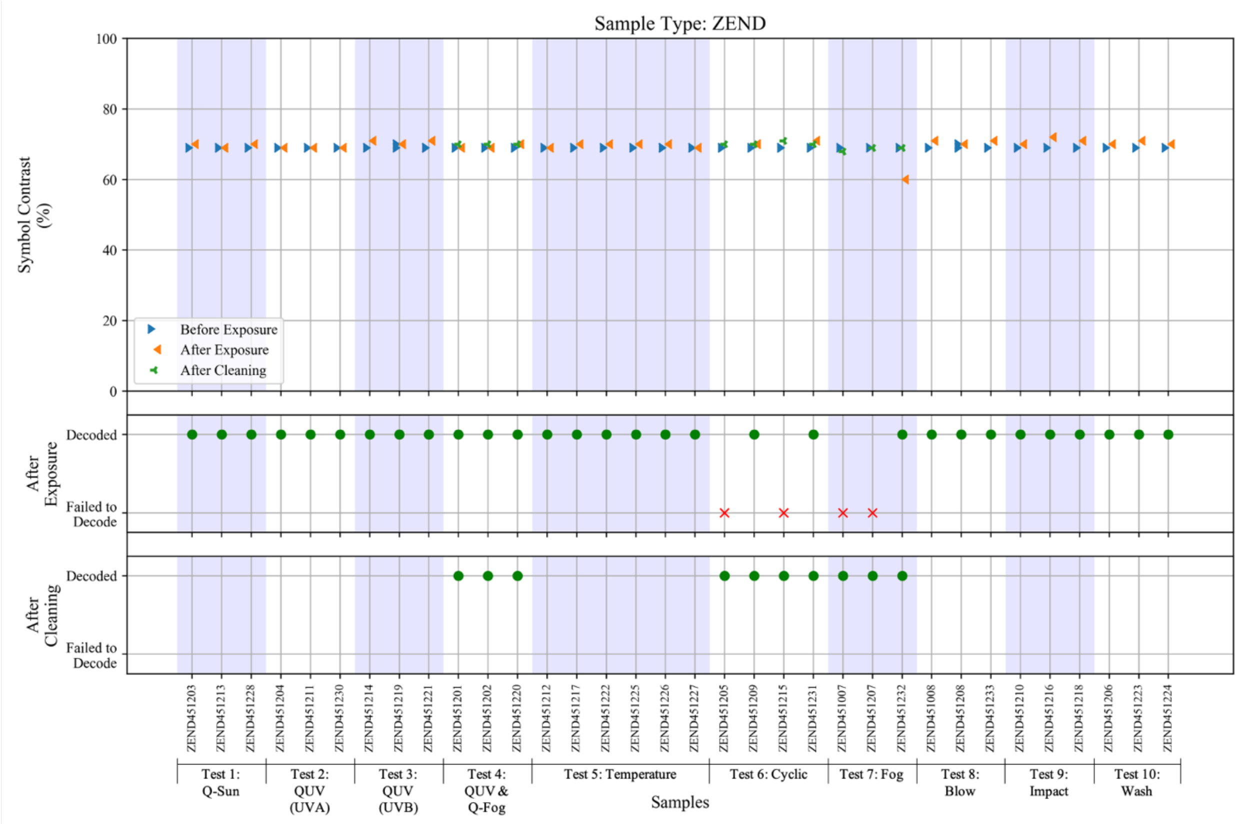


Figure 56. Symbol contrast for Zebra Z-Endure 4000T acrylic label (ZEND) barcode samples before and after all environmental tests.

Across all test types, the ZEND samples showed the most consistent symbol contrast before and after environmental tests. Although a high portion of the samples failed to decode when exposed to corrosion tests (two of the four samples in Test 6 and two of the three samples in Test 7), all seven samples in Tests 6 and 7 decoded after hand cleaning and the resulting increase in symbol contrast demonstrates that the initial decrease after-exposure comes from the coupon rust dust, not from the sample integrity. Note, all 34 ZEND sample identification numbers could be manually read by an ORNL researcher both before and after hand cleaning, regardless of the sample's ability to decode.

5.18 ZULT LABEL-TYPE SAMPLES

Figure 57 shows the symbol contrast metric for the 48 ZULT samples evaluated before and after each environmental test. As shown in the previous sections for tests with corrosion, Tests 4, 6, and 7 also include data points for symbol contrast before and after sample cleaning. The samples subjected to the remaining tests (Tests 1, 2, 3, 5, 8, 9, and 10) were not hand cleaned and rescanned.

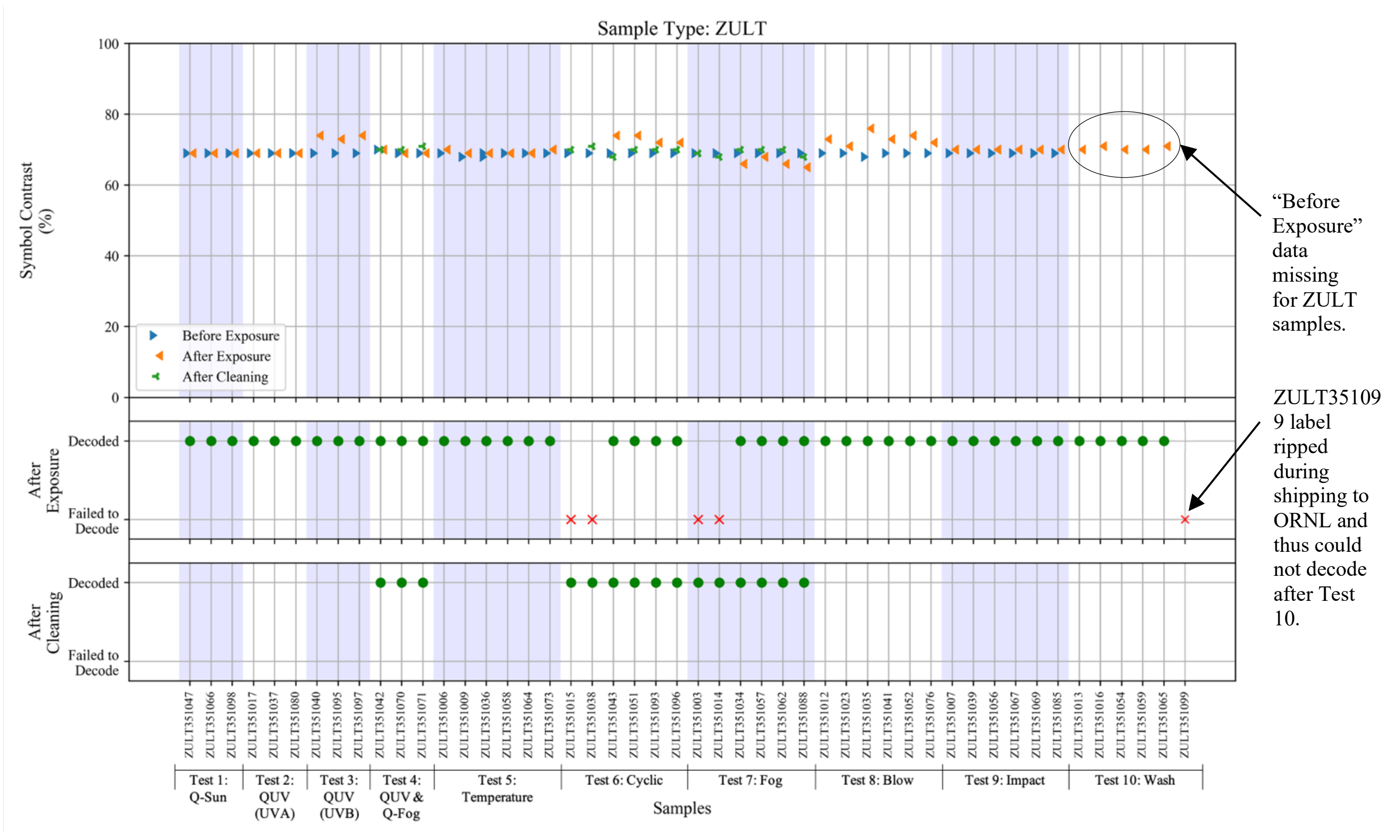


Figure 57. Symbol contrast for Zebra Z-Ultimate 3000T polyester label (ZULT) barcode samples before and after all environmental tests.

Similar to the ZEND samples, the ZULT samples also showed a consistent symbol contrast across all environmental tests. Although a portion of samples failed to decode when exposed to the corrosion tests (2 of the 6 samples in Test 6 and 2 of the 6 samples in Test 7), all 12 samples in Tests 6 and 7 decoded after hand cleaning, and the resulting increase in symbol contrast demonstrates that the initial decrease after-exposure comes from the coupon rust dust, not from the sample integrity. A single sample (ZULT351099) exposed to high pressure and temperature water jet testing failed to decode. The sample was presumably damaged during shipping as a puncture was found in the sample's protective foam sleeve when it was unpacked after testing. Note, all 48 ZULT sample identification numbers could be manually read by an ORNL researcher both before and after hand cleaning, regardless of the sample's ability to decode.

5.19 SUMMARY OF RESULTS BY SAMPLE TYPE

Table 5 summarizes how the contrast from each sample changed after exposure or after subsequent cleaning. This summary very clearly indicates that on average CERM and ZEND samples exhibited increased contrast after exposure, whereas the other samples exhibited reduced contrast. Table 6 through Table 12 describe the contrast each sample type exhibited as a result of each test. The Final Difference column is shown with Excel's conditional formatting green-white-red color scale to help emphasize the relative magnitude of change. Green signifies the contrast improved the most, and red signifies the contrast was reduced the most relative to the original contrast.

Table 5. Summary of contrast values for each sample type before exposure, after exposure, and after cleaning. Sorted from largest contrast decline to smallest.

Sample Type	Before Exposure	After Exposure	After Cleaning	Difference After Exposure	Difference After Cleaning	Final Difference
CERM	84.18	81.61	84.97	(2.56)	—	1.66
ZEND	69.02	69.08	69.64	0.07	—	0.98
ZULT	71.90	70.32	69.78	(1.59)	—	(1.51)
TESA	94.66	91.48	93.17	(3.19)	—	(1.81)
REBO	72.06	69.09	70.78	(2.97)	—	(2.30)
ETCH	96.03	91.11	96.03	(4.92)	—	(2.77)
YAGL	70.91	66.32	65.41	(4.59)	—	(3.25)

Table 6. Contrast values for CERM samples before exposure, after exposure, and after cleaning for each test.

Test	Before Exposure	After Exposure	After Cleaning	Difference After Exposure	Difference After Cleaning	Final Difference
CERM	**84.18**	**81.61**	**84.97**	**(2.56)**	**—**	**1.66**
1 - Q-Sun UV	84.75	90.25	—	5.50	—	5.50
2 - QUV (UVA)	84.31	88.75	—	4.44	—	4.44
3 - QUV (UVB)	83.19	89.75	—	6.56	—	6.56
4 - QUV & Q-FOG	85.40	88.50	91.25	3.10	5.85	5.85
5 - Temp	84.19	82.92	—	(1.27)	—	(1.27)
6 - Cyclic	83.67	60.22	83.93	(23.45)	0.26	0.26
7 - Fog	84.43	64.00	79.73	(20.43)	(4.70)	(4.70)
8 - Blow	84.07	83.91	—	(0.16)	—	(0.16)
9 - Impact	82.68	81.64	—	(1.05)	—	(1.05)
10 - Wash	85.06	86.18	—	1.12	—	1.12

Table 7. Contrast values for ZEND samples before exposure, after exposure and after cleaning for each test.

Test	Before Exposure	After Exposure	After Cleaning	Difference After Exposure	Difference After Cleaning	Final Difference
ZEND	**69.02**	**69.08**	**69.64**	**0.07**	**—**	**0.98**
1 - Q-Sun UV	69.00	69.67	—	0.67	—	0.67
2 - QUV (UVA)	69.00	69.00	—	—	—	—
3 - QUV (UVB)	69.17	70.67	—	1.50	—	1.50
4 - QUV & Q-FOG	69.00	69.33	70.00	0.33	1.00	1.00
5 - Temp	69.00	69.67	—	0.67	—	0.67
6 - Cyclic	69.00	70.50	70.25	1.50	1.25	1.25
7 - Fog	69.00	60.00	68.67	(9.00)	(0.33)	(0.33)
8 - Blow	69.00	70.67	—	1.67	—	1.67
9 - Impact	69.00	71.00	—	2.00	—	2.00
10 - Wash	69.00	70.33	—	1.33	—	1.33

Table 8. Contrast values for ZULT samples before exposure, after exposure and after cleaning for each test.

Test	Before Exposure*	After Exposure	After Cleaning	Difference After Exposure	Difference After Cleaning	Final Difference
ZULT	**71.90**	**70.32**	**69.78**	**(1.59)**	**—**	**(1.51)**
1 - Q-Sun UV	71.83	69.00	—	(2.83)	—	(2.83)
2 - QUV (UVA)	72.17	69.00	—	(3.17)	—	(3.17)
3 - QUV (UVB)	71.83	73.67	—	1.83	—	1.83
4 - QUV & Q-FOG	72.17	69.33	70.33	(2.83)	(1.83)	(1.83)
5 - Temp	71.53	69.33	—	(2.19)	—	(2.19)
6 - Cyclic	71.78	73.00	69.83	1.22	(1.94)	(1.94)
7 - Fog	72.00	66.25	69.17	(5.75)	(2.83)	(2.83)
8 - Blow	72.08	73.17	—	1.08	—	1.08
9 - Impact	71.75	70.00	—	(1.75)	—	(1.75)
10 - Wash	71.90	70.40	—	(1.50)	—	(1.50)

* The before-exposure value for the wash test is highlighted in yellow to help acknowledge that the authors failed to find the before-exposure scans for the ZULT samples subjected to the wash test. To support subsequent quantitative analysis the authors used the average from the before exposure for the other tests as the baseline average value for the pressure wash test.

Table 9. Contrast values for TESA samples before exposure, after exposure, and after cleaning for each test.

Test	Before Exposure	After Exposure	After Cleaning	Difference After Exposure	Difference After Cleaning	Final Difference
TESA	**94.66**	**91.48**	**93.17**	**(3.19)**	**—**	**(1.81)**
1 - Q-Sun UV	94.67	92.67	—	(2.00)	—	(2.00)
2 - QUV (UVA)	94.75	92.00	—	(2.75)	—	(2.75)
3 - QUV (UVB)	94.75	89.67	—	(5.08)	—	(5.08)
4 - QUV & Q-FOG	94.75	91.67	93.33	(3.08)	(1.42)	(1.42)
5 - Temp	94.55	94.17	—	(0.38)	—	(0.38)
6 - Cyclic	94.63	89.83	93.50	(4.80)	(1.13)	(1.13)
7 - Fog	94.79	84.25	92.67	(10.54)	(2.13)	(2.13)
8 - Blow	94.60	92.50	—	(2.10)	—	(2.10)
9 - Impact	94.54	94.00	—	(0.54)	—	(0.54)
10 - Wash	94.60	94.00	—	(0.60)	—	(0.60)

Table 10. Contrast values for REBO samples before exposure, after exposure, and after cleaning for each test.

Test	Before Exposure*	After Exposure	After Cleaning	Difference After Exposure	Difference After Cleaning	Final Difference
REBO	**72.06**	**69.09**	**70.78**	**(2.97)**	**—**	**(2.30)**
1 - Q-Sun UV	72.00	72.00	—	—	—	-
2 - QUV (UVA)	72.33	72.00	—	(0.33)	—	(0.33)
3 - QUV (UVB)	72.33	73.00	—	0.67	—	0.67
4 - QUV & Q-FOG	72.00	71.67	72.33	(0.33)	0.33	0.33
5 - Temp	71.58	48.83	—	(22.75)	—	(22.75)
6 - Cyclic	72.33	70.67	70.17	(1.67)	(2.17)	(2.17)
7 - Fog	72.00	63.25	69.83	(8.75)	(2.17)	(2.17)
8 - Blow	72.00	73.17	—	1.17	—	1.17
9 - Impact	72.00	73.50	—	1.50	—	1.50
10 - Wash	72.06	72.83	—	0.77	—	0.77

* The before-exposure value for the Wash test is highlighted in yellow to help acknowledge that the authors failed to find the before-exposure scans for the REBO samples subjected to the wash test. To support subsequent quantitative analysis the authors used the average from the before exposure for the other tests as the baseline average value for the pressure wash test.

Table 11. Contrast values for ETCH samples before exposure, after exposure, and after cleaning for each test.

Test	Before Exposure	After Exposure	After Cleaning	Difference After Exposure	Difference After Cleaning	Final Difference
ETCH	**96.03**	**91.11**	**96.03**	**(4.92)**	**—**	**(2.77)**
1 - Q-Sun UV	95.92	89.00	—	(6.92)	—	(6.92)
2 - QUV (UVA)	96.19	83.50	—	(12.69)	—	(12.69)
3 - QUV (UVB)	96.19	88.00	—	(8.19)	—	(8.19)
4 - QUV & Q-FOG	96.19	90.00	96.75	(6.19)	0.56	0.56
5 - Temp	95.91	96.58	—	0.67	—	0.67
6 - Cyclic	95.97	93.46	96.77	(2.51)	0.79	0.79
7 - Fog	95.96	83.14	94.58	(12.82)	(1.38)	(1.38)
8 - Blow	95.94	95.25	—	(0.69)	—	(0.69)
9 - Impact	96.01	96.00	—	(0.01)	—	(0.01)
10 - Wash	96.00	96.17	—	0.17	—	0.17

Table 12. Contrast values for YAGL samples before exposure, after exposure, and after cleaning for each test.

Test	Before Exposure	After Exposure	After Cleaning	Difference After Exposure	Difference After Cleaning	Final Difference
YAGL	**70.91**	**66.32**	**65.41**	**(4.59)**	**—**	**(3.25)**
1 - Q-Sun UV	70.67	68.00	—	(2.67)	—	(2.67)
2 - QUV (UVA)	71.48	69.88	—	(1.60)	—	(1.60)
3 - QUV (UVB)	70.94	69.25	—	(1.69)	—	(1.69)
4 - QUV & Q-FOG	71.75	52.67	56.00	(19.08)	(15.75)	(15.75)
5 - Temp	70.27	69.83	—	(0.44)	—	(0.44)
6 - Cyclic	71.38	68.92	72.68	(2.46)	1.30	1.30
7 - Fog	70.67	61.17	67.55	(9.50)	(3.13)	(3.13)
8 - Blow	70.59	67.31	—	(3.28)	—	(3.28)
9 - Impact	70.47	68.67	—	(1.80)	—	(1.80)
10 - Wash	70.87	67.46	—	(3.40)	—	(3.40)

6. CONSIDERATIONS FOR FUTURE WORK

Bare A516 steel surfaces should be painted after the barcode sample is attached. Rust surface residue on many of the sample's caused the verifier to fail to decode barcodes subjected to some tests; however, we believe the observed rust is from the degradation of the bare A516 coupon and not the stainless-steel or label-type samples. The A516 steel used for 30B and 48Y cylinders is painted during fabrication and would not be exposed throughout the remainder of a cylinder's life.

Although the ORNL team expected the untreated surfaces of the A516 steel coupons to rust, the team did not anticipate the rust to transfer to the surfaces of the stainless-steel or label-type samples. This behavior was exceptionally apparent for the samples that underwent QUV and Q-FOG testing (Test 4), cyclic corrosion testing (Test 6), and corrosion testing (Test 7). It did occur to a lesser degree in the samples that were subjected to the UVA and UVB testing (Tests 2 and 3). The authors believe that the rust from the coupons spread onto the barcode from circulating moist air in the test chambers. All but two of the affected samples decoded after a team member cleaned the surface with Formula 409 and WD-40.

Adding a guide to the barcode verifier sped up the team's ability to position barcodes in the verifier's field of view; however, it caused the verifier to fail to decode a few samples. Our team attached an optical breadboard with a grid of tapped holes to the barcode verifier platform. This grid of tapped holes allowed the team to position guide rails to accelerate and standardize positioning barcodes in the verifier's field of view. The optical breadboard and guide rails can be seen in Figure 58. For some barcodes, the verifier initially failed to decode and verify the barcode at the location prescribed by the guides. However, if the sample was shifted slightly or rotated, the barcode could be verified. The team has not observed difficulty decoding 2D barcodes using handheld barcode scanners and believe this behavior is a result of where in the barcode image the verification algorithm tries to start.

Figure 58. Webscan TruCheck DPM Tower with optical breadboard and sample guides attached.

7. DISCUSSION

Under limited-scope environmental testing of 444 samples involving 7 barcode marking techniques, all samples performed relatively equally. However, each sample group has its own strengths and weaknesses. Regardless of the marking technique, all 2D barcodes were successfully decoded after 7 of the 10 environmental tests. Some of the tests caused a decrease in measured cell or symbol contrast, but the exposure was not enough to prevent the barcodes from decoding. All sample types experienced at least one failure to decode after corrosion (salt fog) testing (Test 7), and some sample types experienced at least one failure to decode after QUV and salt fog testing (Test 4) and cyclic corrosion testing (Test 6). After a simple hand cleaning process, all except for three of these samples were successfully decoded. Of these three samples, one (ZULT351099) is suspected to have ripped during shipping, although it was not immediately clear why the other two samples (YAGL123476 and YAGL123486) did not decode. Regardless of the sample's ability to decode postexposure, all sample identification numbers could be manually read by an ORNL researcher both before and after hand cleaning.

Additionally, the coupon attachment method did not appear to influence the sample's ability to decode, and there was not a clear advantage for the use of one sample type (stainless-steel or label-type) over the other. Anecdotal evidence suggests that chemically etched and paint filled markings and epoxy adhesives fail over time, but this testing campaign did not reveal evidence to support these observations. Any of the label-type samples (REBO, TESA, ZEND, and ZULT) could provide an easy to apply solution as a global identifier label that supplements current identification plates on UF_6 cylinders in circulation before they are due for recertification.

The highest contrast readings across all environmental tests were demonstrated by ETCH (stainless-steel type) and TESA (label-type) samples, but the ZEND and ZULT label-type samples had the most consistent contrast readings before and after environmental exposure. Overall, each of the seven barcode marking techniques are reasonable candidates for use in the field following limited-scope environmental testing. A summary of the advantages and weaknesses for each sample type is shown in Table 13.

Table 13. Strengths and weaknesses of sample types exposed to environmental testing.

Sample Type	Stainless-Steel or Label-Type	Advantage	Weakness
CERM	Stainless-Steel	High Cell Contrast	Corrosion Tests
ETCH	Stainless-Steel	High Cell Contrast	UV Tests (all)
YAGL	Stainless-Steel	None	Corrosion Tests and Moderate Cell Contrast
REBO	Label-Type	Symbol Contrast Consistency	Temperature Tests and Moderate Symbol Contrast
TESA	Label-Type	High Cell Contrast and Consistency	UVB Tests
ZEND	Label-Type	Symbol Contrast Consistency	Moderate Symbol Contrast
ZULT	Label-Type	Symbol Contrast Consistency	Moderate Symbol Contrast

[1] High Cell or Symbol Contrast: 80% or above
Moderate Cell or Symbol Contrast: 60%–80%
Low Cell or Symbol Contrast: 60% or below

Generally, the label-type samples had a smaller decrease in symbol contrast after environmental exposure.

Overall, the ZEND and ZULT sample sets demonstrated the most consistent symbol contrast for all 10 environmental tests. Each remaining sample set was susceptible to at least one type of environmental exposure. Although all REBO labels decoded after the temperature testing, the label discoloration was unique to this sample set and caused a significant decrease in symbol contrast. Similarly, the ETCH samples performed poorly for all UV based tests when compared to other stainless-steel samples. Additionally, it appeared that the TESA tape samples were susceptible to UVB exposure, but they did not show a similar decrease in cell contrast for other UV tests. Despite their susceptibility to the abovementioned exposures, the ETCH and TESA samples had the highest overall contrast values compared to the other sample types.

Any coupon rust presented issues for all sample types. Specifically, many CERM and YAGL samples failed to decode after corrosion tests (Tests 6 and 7). Fewer than half of the samples from each set could be decoded before hand cleaning. After hand cleaning, the YAGL sample set consistently preformed more poorly than the others. It would have been more representative to paint or otherwise treat the bare A516 to better represent the conditions of cylinders in the field.

8. CONCLUSIONS

The postexposure results described in this report suggest that of the sample types tested, ball-blasted stainless-steel sheets laser marked with CerMark laser marking ink (CERM) would be the most robust material and marking technique for UF_6 supplemental cylinder identifiers. Although stainless-steel supplemental cylinder identifiers could be welded or affixed using epoxies such as the Aremco 517 epoxy, thermal printer-based labels like the Zebra Z-Ultimate 3000T (ZULT) offer an alternative that are extremely easy to affix to a surface, very cost effective to produce on-site (suitable industrial label printers cost about $1,500 and consumables cost about $0.10 per label) and were nearly as robust as the top performing CERM samples. Although ZEND (Z-Endure 4000T) slightly outperformed the ZULT labels and the manufacturer rates them for 10-year use outside compared to 3 years for the Z-Ultimate 3000T labels, Z-Endure 4000T are special order and exhibited the printing flaws described in Section 2. Table 14 summarizes our conclusion for all the sample types.

Table 14. Summary of samples tested and conclusions based on quantitative and qualitative analysis of the results.

Sample Type	Conclusion	Sample Description	Conclusion Explanation
CERM	Highly recommended	Ball-blasted stainless-steel sheets laser marked with CerMark laser marking ink	Best average contrast change. Contrast increased after UV exposure tests (Tests 1, 2, 3, and 4) and only decreased slightly for salt fog (Test 7).
ZULT	Recommended label alternative to stainless steel	Zebra Z-Ultimate 3000T polyester labels	Affordable, widely available stainless steel alternative label material that performed nearly as well as the ZEND
ZEND	Recommended label alternative to stainless steel	Zebra Z-Endure 4000T acrylic labels	May be challenging to procure but may offer more robustness than other labels.
TESA	Acceptable	Tesa Secure 6973 tape	Appears to offer little benefit compared to more widely available polyester or acrylic labels and requires more complicated and expensive marking system.
ETCH	Acceptable	Ball-blasted stainless-steel sheets chemically etched with etched areas filled with paint	Appears to offer little benefit compared to more widely available polyester or acrylic labels and requires more complicated and expensive marking system.
REBO	Not recommended	Rebo ST700 Premium Industrial Vinyl	Discolored considerably during temperature testing.
YAGL	Not recommended	Ball-blasted stainless-steel sheets marked with YAG laser	Contrast decreased significantly during QUV and Q-FOG test (Test 4), but some samples subjected to salt fog (Test 7) remained undecodable even after cleaning.

9. ACKNOWLEDGMENTS

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APPENDIX A. EPOXY PREPARATION

APPENDIX A. EPOXY PREPARATION

Figures A-1 through A-6 illustrate the process used to epoxy the stainless-steel samples to the A516 coupons. A total of 116 samples were epoxied using this process.

Figure A-1. Epoxy is expelled until both sides are flowing from the tube.

Figure A-2. A nozzle is installed, and the epoxy is expelled until it flows freely from the nozzle.

Figure A-3. The stainless-steel barcode sample is positioned in a template cut to the size of the A516 coupon. Epoxy is then expelled onto the back of the sample.

Figure A-4. A disposable notched trowel is used to ensure an even coating of epoxy on the back of the sample.

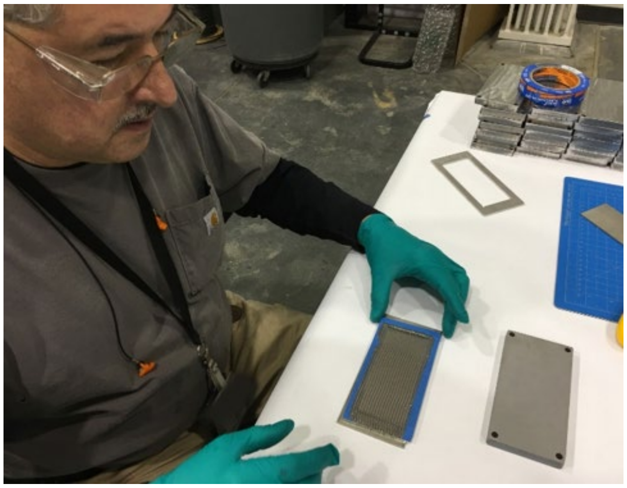

Figure A-5. At this point, the stainless-steel barcode sample has a uniform amount of epoxy distributed across the surface and the technician can flip the A516 coupon onto the sample.

Figure A-6. Once the template (as shown in the technician's left hand) is removed, the stainless-steel barcode sample is left on the A516 coupon in a consistent position.

APPENDIX B. BARCODE SAMPLES GROUPED BY SAMPLE TYPE

APPENDIX B. BARCODE SAMPLES GROUPED BY SAMPLE TYPE

Tables B-1 through B-7 provide information on each sample with the seven sample types including sample ID, type of environmental test performed, coupon finish, and attachment method.

Table B-1. 87 CerMark-coated laser-marked stainless-steel barcode samples and associated environmental tests.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
CERM123400	5 - Temperature	Free	Free
CERM123401	10 - Wash	Free	Free
CERM123402	2 - QUV (UVA)	Polished	Weld
CERM123403	7 - Corrosion (Fog)	Free	Free
CERM123404	5 - Temperature	Sandblasted	Aremco 517 Epoxy
CERM123405	6 - Cyclic	Free	Free
CERM123406	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
CERM123407	9 - Impact	Free	Free
CERM123409	8 - Blow	Free	Free
CERM123410	8 - Blow	Sandblasted	Aremco 517 Epoxy
CERM123411	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
CERM123412	7 - Corrosion (Fog)	Free	Free
CERM123413	1 - Q-SUN	Free	Free
CERM123414	4 - QUV & Q-FOG	Polished	Weld
CERM123416	10 - Wash	Sandblasted	Aremco 517 Epoxy
CERM123417	5 - Temperature	Free	Free
CERM123418	8 - Blow	Free	Free
CERM123419	6 - Cyclic	Polished	Aremco 517 Epoxy
CERM123420	7 - Corrosion (Fog)	Free	Free
CERM123421	5 - Temperature	Sandblasted	Aremco 517 Epoxy
CERM123422	1 - Q-SUN	Polished	Aremco 517 Epoxy
CERM123423	6 - Cyclic	Free	Free
CERM123424	8 - Blow	Sandblasted	Aremco 517 Epoxy
CERM123425	4 - QUV & Q-FOG	Sandblasted	Aremco 517 Epoxy
CERM123426	5 - Temperature	Free	Free
CERM123427	10 - Wash	Free	Free
CERM123428	9 - Impact	Free	Free
CERM123430	10 - Wash	Sandblasted	Aremco 517 Epoxy
CERM123431	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
CERM123432	2 - QUV (UVA)	Free	Free
CERM123433	8 - Blow	Sandblasted	Aremco 517 Epoxy
CERM123434	5 - Temperature	Sandblasted	Aremco 517 Epoxy
CERM123435	8 - Blow	Free	Free
CERM123436	3 - QUV (UVB)	Sandblasted	Aremco 517 Epoxy
CERM123438	3 - QUV (UVB)	Free	Free
CERM123440	9 - Impact	Sandblasted	Aremco 517 Epoxy
CERM123441	4 - QUV & Q-FOG	Free	Free

Table B-1. 87 CerMark-coated laser-marked stainless-steel barcode samples and associated environmental tests, continued.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
CERM123443	10 - Wash	Free	Free
CERM123444	5 - Temperature	Polished	Aremco 517 Epoxy
CERM123445	10 - Wash	Free	Free
CERM123446	1 - Q-SUN	Polished	Weld
CERM123447	8 - Blow	Free	Free
CERM123448	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
CERM123449	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
CERM123450	4 - QUV & Q-FOG	Polished	Aremco 517 Epoxy
CERM123451	10 - Wash	Sandblasted	Aremco 517 Epoxy
CERM123452	6 - Cyclic	Polished	Weld
CERM123454	6 - Cyclic	Polished	Weld
CERM123457	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
CERM123458	9 - Impact	Free	Free
CERM123459	6 - Cyclic	Free	Free
CERM123460	2 - QUV (UVA)	Polished	Aremco 517 Epoxy
CERM123461	10 - Wash	Polished	Weld
CERM123462	7 - Corrosion (Fog)	Free	Free
CERM123464	8 - Blow	Polished	Weld
CERM123465	3 - QUV (UVB)	Polished	Weld
CERM123466	9 - Impact	Sandblasted	Aremco 517 Epoxy
CERM123467	10 - Wash	Free	Free
CERM123468	5 - Temperature	Free	Free
CERM123469	8 - Blow	Sandblasted	Aremco 517 Epoxy
CERM123470	10 - Wash	Polished	Weld
CERM123471	7 - Corrosion (Fog)	Polished	Weld
CERM123472	10 - Wash	Sandblasted	Aremco 517 Epoxy
CERM123473	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
CERM123475	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
CERM123476	8 - Blow	Polished	Weld
CERM123478	5 - Temperature	Polished	Weld
CERM123479	9 - Impact	Sandblasted	Aremco 517 Epoxy
CERM123480	7 - Corrosion (Fog)	Polished	Weld
CERM123481	5 - Temperature	Polished	Aremco 517 Epoxy
CERM123482	9 - Impact	Sandblasted	Aremco 517 Epoxy
CERM123483	7 - Corrosion (Fog)	Free	Free
CERM123484	5 - Temperature	Free	Free
CERM123485	9 - Impact	Polished	Weld
CERM123487	8 - Blow	Free	Free
CERM123488	2 - QUV (UVA)	Sandblasted	Aremco 517 Epoxy
CERM123489	9 - Impact	Free	Free
CERM123490	5 - Temperature	Sandblasted	Aremco 517 Epoxy

Table B-1. 87 CerMark-coated laser-marked stainless-steel barcode samples and associated environmental tests, continued.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
CERM123491	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
CERM123492	9 - Impact	Free	Free
CERM123493	9 - Impact	Polished	Weld
CERM123494	6 - Cyclic	Free	Free
CERM123495	1 - Q-SUN	Sandblasted	Aremco 517 Epoxy
CERM123496	6 - Cyclic	Free	Free
CERM123497	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
CERM123498	5 - Temperature	Sandblasted	Aremco 517 Epoxy
CERM123499	3 - QUV (UVB)	Polished	Aremco 517 Epoxy

Table B-2. 87 chemically etched stainless-steel barcode samples and associated environmental tests.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
ETCH123400	9 - Impact	Polished	Weld
ETCH123401	9 - Impact	Free	Free
ETCH123402	4 - QUV & Q-FOG	Polished	Aremco 517 Epoxy
ETCH123403	9 - Impact	Sandblasted	Aremco 517 Epoxy
ETCH123404	10 - Wash	Sandblasted	Aremco 517 Epoxy
ETCH123405	5 - Temperature	Free	Free
ETCH123406	4 - QUV & Q-FOG	Sandblasted	Aremco 517 Epoxy
ETCH123407	3 - QUV (UVB)	Free	Free
ETCH123408	8 - Blow	Sandblasted	Aremco 517 Epoxy
ETCH123409	2 - QUV (UVA)	Polished	Aremco 517 Epoxy
ETCH123410	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
ETCH123411	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
ETCH123412	4 - QUV & Q-FOG	Free	Free
ETCH123413	8 - Blow	Polished	Weld
ETCH123414	6 - Cyclic	Free	Free
ETCH123415	5 - Temperature	Free	Free
ETCH123416	1 - Q-SUN	Polished	Aremco 517 Epoxy
ETCH123417	7 - Corrosion (Fog)	Free	Free
ETCH123419	8 - Blow	Free	Free
ETCH123420	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
ETCH123421	7 - Corrosion (Fog)	Free	Free
ETCH123422	2 - QUV (UVA)	Free	Free
ETCH123423	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
ETCH123424	9 - Impact	Free	Free
ETCH123425	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
ETCH123426	5 - Temperature	Sandblasted	Aremco 517 Epoxy
ETCH123427	6 - Cyclic	Free	Free
ETCH123429	9 - Impact	Free	Free
ETCH123430	2 - QUV (UVA)	Sandblasted	Aremco 517 Epoxy
ETCH123431	4 - QUV & Q-FOG	Polished	Weld
ETCH123434	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
ETCH123436	6 - Cyclic	Polished	Weld
ETCH123437	3 - QUV (UVB)	Polished	Weld
ETCH123438	1 - Q-SUN	Sandblasted	Aremco 517 Epoxy
ETCH123439	9 - Impact	Sandblasted	Aremco 517 Epoxy
ETCH123441	9 - Impact	Sandblasted	Aremco 517 Epoxy
ETCH123442	8 - Blow	Sandblasted	Aremco 517 Epoxy
ETCH123443	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
ETCH123444	10 - Wash	Free	Free
ETCH123445	7 - Corrosion (Fog)	Polished	Weld
ETCH123446	5 - Temperature	Free	Free

Table B-2. 87 chemically etched stainless-steel barcode samples and associated environmental tests, continued.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
ETCH123447	10 - Wash	Free	Free
ETCH123448	6 - Cyclic	Polished	Aremco 517 Epoxy
ETCH123449	10 - Wash	Sandblasted	Aremco 517 Epoxy
ETCH123450	6 - Cyclic	Free	Free
ETCH123451	10 - Wash	Free	Free
ETCH123452	10 - Wash	Free	Free
ETCH123454	5 - Temperature	Sandblasted	Aremco 517 Epoxy
ETCH123457	8 - Blow	Free	Free
ETCH123458	7 - Corrosion (Fog)	Polished	Weld
ETCH123459	10 - Wash	Polished	Weld
ETCH123460	8 - Blow	Free	Free
ETCH123461	10 - Wash	Free	Free
ETCH123463	9 - Impact	Free	Free
ETCH123464	6 - Cyclic	Free	Free
ETCH123466	9 - Impact	Polished	Weld
ETCH123467	10 - Wash	Polished	Weld
ETCH123468	10 - Wash	Sandblasted	Aremco 517 Epoxy
ETCH123469	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
ETCH123470	9 - Impact	Free	Free
ETCH123471	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
ETCH123472	5 - Temperature	Free	Free
ETCH123473	2 - QUV (UVA)	Polished	Weld
ETCH123474	10 - Wash	Sandblasted	Aremco 517 Epoxy
ETCH123475	8 - Blow	Sandblasted	Aremco 517 Epoxy
ETCH123476	7 - Corrosion (Fog)	Free	Free
ETCH123477	5 - Temperature	Polished	Weld
ETCH123478	6 - Cyclic	Polished	Weld
ETCH123479	8 - Blow	Sandblasted	Aremco 517 Epoxy
ETCH123480	1 - Q-SUN	Polished	Weld
ETCH123481	5 - Temperature	Free	Free
ETCH123482	10 - Wash	Sandblasted	Aremco 517 Epoxy
ETCH123483	5 - Temperature	Sandblasted	Aremco 517 Epoxy
ETCH123484	7 - Corrosion (Fog)	Free	Free
ETCH123485	5 - Temperature	Polished	Aremco 517 Epoxy
ETCH123487	9 - Impact	Sandblasted	Aremco 517 Epoxy
ETCH123489	8 - Blow	Sandblasted	Aremco 517 Epoxy
ETCH123490	8 - Blow	Free	Free
ETCH123491	6 - Cyclic	Free	Free
ETCH123492	8 - Blow	Polished	Weld
ETCH123493	3 - QUV (UVB)	Polished	Aremco 517 Epoxy

Table B-2. 87 chemically etched stainless-steel barcode samples and associated environmental tests, continued.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
ETCH123494	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
ETCH123495	7 - Corrosion (Fog)	Free	Free
ETCH123496	8 - Blow	Free	Free
ETCH123497	3 - QUV (UVB)	Sandblasted	Aremco 517 Epoxy
ETCH123498	5 - Temperature	Sandblasted	Aremco 517 Epoxy
ETCH123499	5 - Temperature	Sandblasted	Aremco 517 Epoxy

Table B-3. 92 laser-marked stainless-steel barcode samples and associated environmental tests.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
YAGL123400	9 - Impact	Sandblasted	Aremco 517 Epoxy
YAGL123401	8 - Blow	Free	Free
YAGL123402	5 - Temperature	Free	Free
YAGL123403	7 - Corrosion (Fog)	Free	Free
YAGL123405	8 - Blow	Sandblasted	Aremco 517 Epoxy
YAGL123406	10 - Wash	Free	Free
YAGL123407	8 - Blow	Sandblasted	Aremco 517 Epoxy
YAGL123408	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
YAGL123409	5 - Temperature	Polished	Weld
YAGL123410	9 - Impact	Sandblasted	Aremco 517 Epoxy
YAGL123411	9 - Impact	Free	Free
YAGL123412	4 - QUV & Q-FOG	Polished	Weld
YAGL123414	8 - Blow	Polished	Weld
YAGL123415	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
YAGL123416	1 - Q-SUN	Sandblasted	Aremco 517 Epoxy
YAGL123417	10 - Wash	Free	Free
YAGL123418	5 - Temperature	Free	Free
YAGL123419	9 - Impact	Free	Free
YAGL123420	8 - Blow	Sandblasted	Aremco 517 Epoxy
YAGL123422	9 - Impact	Sandblasted	Aremco 517 Epoxy
YAGL123423	10 - Wash	Sandblasted	Aremco 517 Epoxy
YAGL123424	5 - Temperature	Polished	Aremco 517 Epoxy
YAGL123425	5 - Temperature	Sandblasted	Aremco 517 Epoxy
YAGL123426	8 - Blow	Sandblasted	Aremco 517 Epoxy
YAGL123427	7 - Corrosion (Fog)	Free	Free
YAGL123428	10 - Wash	Free	Free
YAGL123429	10 - Wash	Sandblasted	Aremco 517 Epoxy
YAGL123430	6 - Cyclic	Free	Free
YAGL123432	5 - Temperature	Sandblasted	Aremco 517 Epoxy
YAGL123433	8 - Blow	Sandblasted	Aremco 517 Epoxy
YAGL123434	5 - Temperature	Free	Free
YAGL123435	9 - Impact	Polished	Weld
YAGL123437	3 - QUV (UVB)	Polished	Weld
YAGL123439	7 - Corrosion (Fog)	Free	Free
YAGL123440	3 - QUV (UVB)	Polished	Aremco 517 Epoxy
YAGL123441	9 - Impact	Free	Free
YAGL123442	8 - Blow	Free	Free
YAGL123443	10 - Wash	Free	Free
YAGL123444	8 - Blow	Free	Free
YAGL123445	9 - Impact	Sandblasted	Aremco 517 Epoxy
YAGL123446	9 - Impact	Polished	Weld

Table B-3. 92 laser-marked stainless-steel barcode samples and associated environmental tests, continued.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
YAGL123447	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
YAGL123448	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
YAGL123449	10 - Wash	Free	Free
YAGL123450	5 - Temperature	Free	Free
YAGL123451	10 - Wash	Polished	Weld
YAGL123452	8 - Blow	Free	Free
YAGL123453	6 - Cyclic	Polished	Weld
YAGL123455	7 - Corrosion (Fog)	Free	Free
YAGL123456	7 - Corrosion (Fog)	Free	Free
YAGL123457	1 - Q-SUN	Polished	Weld
YAGL123458	2 - QUV (UVA)	Polished	Weld
YAGL123459	2 - QUV (UVA)	Polished	Aremco 517 Epoxy
YAGL123460	2 - QUV (UVA)	Free	Free
YAGL123461	4 - QUV & Q-FOG	Free	Free
YAGL123462	4 - QUV & Q-FOG	Polished	Aremco 517 Epoxy
YAGL123463	5 - Temperature	Free	Free
YAGL123464	5 - Temperature	Sandblasted	Aremco 517 Epoxy
YAGL123465	8 - Blow	Free	Free
YAGL123466	10 - Wash	Free	Free
YAGL123467	6 - Cyclic	Free	Free
YAGL123468	6 - Cyclic	Free	Free
YAGL123469	9 - Impact	Free	Free
YAGL123470	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
YAGL123471	10 - Wash	Sandblasted	Aremco 517 Epoxy
YAGL123472	7 - Corrosion (Fog)	Free	Free
YAGL123473	3 - QUV (UVB)	Sandblasted	Aremco 517 Epoxy
YAGL123474	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
YAGL123475	5 - Temperature	Sandblasted	Aremco 517 Epoxy
YAGL123476	7 - Corrosion (Fog)	Polished	Weld
YAGL123477	6 - Cyclic	Polished	Aremco 517 Epoxy
YAGL123478	6 - Cyclic	Free	Free
YAGL123479	9 - Impact	Free	Free
YAGL123480	5 - Temperature	Sandblasted	Aremco 517 Epoxy
YAGL123481	7 - Corrosion (Fog)	Polished	Weld
YAGL123482	6 - Cyclic	Free	Free
YAGL123483	9 - Impact	Free	Free
YAGL123484	8 - Blow	Polished	Weld
YAGL123485	10 - Wash	Sandblasted	Aremco 517 Epoxy
YAGL123486	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
YAGL123488	2 - QUV (UVA)	Sandblasted	Aremco 517 Epoxy
YAGL123489	6 - Cyclic	Sandblasted	Aremco 517 Epoxy

Table B-3. 92 laser-marked stainless-steel barcode samples and associated environmental tests, continued.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
YAGL123490	3 - QUV (UVB)	Free	Free
YAGL123491	6 - Cyclic	Sandblasted	Aremco 517 Epoxy
YAGL123492	8 - Blow	Free	Free
YAGL123493	1 - Q-SUN	Polished	Aremco 517 Epoxy
YAGL123494	10 - Wash	Sandblasted	Aremco 517 Epoxy
YAGL123495	10 - Wash	Polished	Weld
YAGL123496	7 - Corrosion (Fog)	Sandblasted	Aremco 517 Epoxy
YAGL123497	6 - Cyclic	Polished	Weld
YAGL123498	6 - Cyclic	Free	Free
YAGL123499	4 - QUV & Q-FOG	Sandblasted	Aremco 517 Epoxy

Table B-4. 48 Rebo premium vinyl labels and associated environmental tests.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
REBO123402	6 - Cyclic	Polished	Self-Adhered
REBO123408	1 - Q-SUN	Sandblasted	Self-Adhered
REBO123411	10 - Wash	Sandblasted	Self-Adhered
REBO123412	5 - Temperature	Sandblasted	Self-Adhered
REBO123413	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
REBO123415	6 - Cyclic	Sandblasted	Self-Adhered
REBO123416	6 - Cyclic	Sandblasted	Self-Adhered
REBO123418	6 - Cyclic	Sandblasted	Self-Adhered
REBO123420	9 - Impact	Sandblasted	Self-Adhered
REBO123421	1 - Q-SUN	Polished	Self-Adhered
REBO123424	2 - QUV (UVA)	Polished	Self-Adhered
REBO123425	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
REBO123427	4 - QUV & Q-FOG	Polished	Self-Adhered
REBO123428	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
REBO123429	2 - QUV (UVA)	Sandblasted	Self-Adhered
REBO123430	8 - Blow	Sandblasted	Self-Adhered
REBO123433	8 - Blow	Sandblasted	Self-Adhered
REBO123436	10 - Wash	Sandblasted	Self-Adhered
REBO123439	10 - Wash	Sandblasted	Self-Adhered
REBO123441	6 - Cyclic	Sandblasted	Self-Adhered
REBO123442	4 - QUV & Q-FOG	Sandblasted	Self-Adhered
REBO123444	10 - Wash	Sandblasted	Self-Adhered
REBO123448	6 - Cyclic	Sandblasted	Self-Adhered
REBO123450	9 - Impact	Sandblasted	Self-Adhered
REBO123451	3 - QUV (UVB)	Sandblasted	Self-Adhered
REBO123452	3 - QUV (UVB)	Sandblasted	Self-Adhered
REBO123453	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
REBO123454	9 - Impact	Sandblasted	Self-Adhered
REBO123455	1 - Q-SUN	Sandblasted	Self-Adhered
REBO123456	4 - QUV & Q-FOG	Sandblasted	Self-Adhered
REBO123457	5 - Temperature	Sandblasted	Self-Adhered
REBO123462	9 - Impact	Sandblasted	Self-Adhered
REBO123463	5 - Temperature	Sandblasted	Self-Adhered
REBO123466	2 - QUV (UVA)	Sandblasted	Self-Adhered
REBO123467	5 - Temperature	Sandblasted	Self-Adhered
REBO123468	9 - Impact	Sandblasted	Self-Adhered
REBO123470	3 - QUV (UVB)	Polished	Self-Adhered
REBO123471	8 - Blow	Sandblasted	Self-Adhered
REBO123474	10 - Wash	Sandblasted	Self-Adhered
REBO123476	9 - Impact	Sandblasted	Self-Adhered
REBO123477	5 - Temperature	Sandblasted	Self-Adhered

Table B-4. 48 Rebo premium vinyl labels and associated environmental tests, continued.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
REBO123479	8 - Blow	Sandblasted	Self-Adhered
REBO123482	8 - Blow	Sandblasted	Self-Adhered
REBO123490	5 - Temperature	Polished	Self-Adhered
REBO123492	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
REBO123494	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
REBO123495	10 - Wash	Sandblasted	Self-Adhered
REBO123496	8 - Blow	Sandblasted	Self-Adhered

Table B-5. 48 Laser-marked Tesa tape samples and associated environmental tests.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
TESA123402	6 - Cyclic	Sandblasted	Self-Adhered
TESA123406	3 - QUV (UVB)	Sandblasted	Self-Adhered
TESA123407	9 - Impact	Sandblasted	Self-Adhered
TESA123409	2 - QUV (UVA)	Sandblasted	Self-Adhered
TESA123410	10 - Wash	Sandblasted	Self-Adhered
TESA123411	10 - Wash	Sandblasted	Self-Adhered
TESA123412	9 - Impact	Sandblasted	Self-Adhered
TESA123414	2 - QUV (UVA)	Polished	Self-Adhered
TESA123415	4 - QUV & Q-FOG	Sandblasted	Self-Adhered
TESA123418	9 – Impact	Sandblasted	Self-Adhered
TESA123420	4 - QUV & Q-FOG	Sandblasted	Self-Adhered
TESA123421	5 - Temperature	Polished	Self-Adhered
TESA123422	8 - Blow	Sandblasted	Self-Adhered
TESA123423	10 - Wash	Sandblasted	Self-Adhered
TESA123425	2 - QUV (UVA)	Sandblasted	Self-Adhered
TESA123427	8 - Blow	Sandblasted	Self-Adhered
TESA123429	6 - Cyclic	Polished	Self-Adhered
TESA123430	6 - Cyclic	Sandblasted	Self-Adhered
TESA123431	6 - Cyclic	Sandblasted	Self-Adhered
TESA123433	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
TESA123437	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
TESA123438	5 - Temperature	Sandblasted	Self-Adhered
TESA123441	3 - QUV (UVB)	Sandblasted	Self-Adhered
TESA123442	9 - Impact	Sandblasted	Self-Adhered
TESA123444	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
TESA123445	1 - Q-SUN	Polished	Self-Adhered
TESA123449	10 - Wash	Sandblasted	Self-Adhered
TESA123454	1 - Q-SUN	Sandblasted	Self-Adhered
TESA123456	6 - Cyclic	Sandblasted	Self-Adhered
TESA123457	8 - Blow	Sandblasted	Self-Adhered
TESA123460	5 - Temperature	Sandblasted	Self-Adhered
TESA123462	5 - Temperature	Sandblasted	Self-Adhered
TESA123463	5 - Temperature	Sandblasted	Self-Adhered
TESA123465	1 - Q-SUN	Sandblasted	Self-Adhered
TESA123468	8 - Blow	Sandblasted	Self-Adhered
TESA123469	8 - Blow	Sandblasted	Self-Adhered
TESA123470	4 - QUV & Q-FOG	Polished	Self-Adhered
TESA123472	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
TESA123473	5 - Temperature	Sandblasted	Self-Adhered
TESA123475	8 - Blow	Sandblasted	Self-Adhered
TESA123478	3 - QUV (UVB)	Polished	Self-Adhered
TESA123483	9 - Impact	Sandblasted	Self-Adhered

Table B-5. 48 Laser-marked Tesa tape samples and associated environmental tests, continued.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
TESA123486	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
TESA123488	10 - Wash	Sandblasted	Self-Adhered
TESA123491	6 - Cyclic	Sandblasted	Self-Adhered
TESA123493	10 - Wash	Sandblasted	Self-Adhered
TESA123494	9 - Impact	Sandblasted	Self-Adhered
TESA123498	7 - Corrosion (Fog)	Sandblasted	Self-Adhered

Table B-6. 34 Zebra Z-Endure 4000T labels and associated environmental tests.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
ZEND451007	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
ZEND451008	8 - Blow	Sandblasted	Self-Adhered
ZEND451201	4 - QUV & Q-FOG	Sandblasted	Self-Adhered
ZEND451202	4 - QUV & Q-FOG	Polished	Self-Adhered
ZEND451203	1 - Q-SUN	Sandblasted	Self-Adhered
ZEND451204	2 - QUV (UVA)	Sandblasted	Self-Adhered
ZEND451205	6 - Cyclic	Sandblasted	Self-Adhered
ZEND451206	10 - Wash	Sandblasted	Self-Adhered
ZEND451207	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
ZEND451208	8 - Blow	Sandblasted	Self-Adhered
ZEND451209	6 - Cyclic	Sandblasted	Self-Adhered
ZEND451210	9 - Impact	Sandblasted	Self-Adhered
ZEND451211	2 - QUV (UVA)	Sandblasted	Self-Adhered
ZEND451212	5 - Temperature	Sandblasted	Self-Adhered
ZEND451213	1 - Q-SUN	Sandblasted	Self-Adhered
ZEND451214	3 - QUV (UVB)	Polished	Self-Adhered
ZEND451215	6 - Cyclic	Polished	Self-Adhered
ZEND451216	9 - Impact	Sandblasted	Self-Adhered
ZEND451217	5 - Temperature	Sandblasted	Self-Adhered
ZEND451218	9 - Impact	Sandblasted	Self-Adhered
ZEND451219	3 - QUV (UVB)	Sandblasted	Self-Adhered
ZEND451220	4 - QUV & Q-FOG	Sandblasted	Self-Adhered
ZEND451221	3 - QUV (UVB)	Sandblasted	Self-Adhered
ZEND451222	5 - Temperature	Sandblasted	Self-Adhered
ZEND451223	10 - Wash	Sandblasted	Self-Adhered
ZEND451224	10 - Wash	Sandblasted	Self-Adhered
ZEND451225	5 - Temperature	Sandblasted	Self-Adhered
ZEND451226	5 - Temperature	Polished	Self-Adhered
ZEND451227	5 - Temperature	Sandblasted	Self-Adhered
ZEND451228	1 - Q-SUN	Polished	Self-Adhered
ZEND451230	2 - QUV (UVA)	Polished	Self-Adhered
ZEND451231	6 - Cyclic	Sandblasted	Self-Adhered
ZEND451232	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
ZEND451233	8 - Blow	Sandblasted	Self-Adhered

Table B-7. 48 Zebra Z-Ultimate 3000T labels and associated environmental tests.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
ZULT351003	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
ZULT351006	5 - Temperature	Sandblasted	Self-Adhered
ZULT351007	9 - Impact	Sandblasted	Self-Adhered
ZULT351009	5 - Temperature	Sandblasted	Self-Adhered
ZULT351012	8 - Blow	Sandblasted	Self-Adhered
ZULT351013	10 - Wash	Sandblasted	Self-Adhered
ZULT351014	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
ZULT351015	6 - Cyclic	Sandblasted	Self-Adhered
ZULT351016	10 - Wash	Sandblasted	Self-Adhered
ZULT351017	2 - QUV (UVA)	Sandblasted	Self-Adhered
ZULT351023	8 - Blow	Sandblasted	Self-Adhered
ZULT351034	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
ZULT351035	8 - Blow	Sandblasted	Self-Adhered
ZULT351036	5 - Temperature	Polished	Self-Adhered
ZULT351037	2 - QUV (UVA)	Sandblasted	Self-Adhered
ZULT351038	6 - Cyclic	Sandblasted	Self-Adhered
ZULT351039	9 - Impact	Sandblasted	Self-Adhered
ZULT351040	3 - QUV (UVB)	Sandblasted	Self-Adhered
ZULT351041	8 - Blow	Sandblasted	Self-Adhered
ZULT351042	4 - QUV & Q-FOG	Polished	Self-Adhered
ZULT351043	6 - Cyclic	Sandblasted	Self-Adhered
ZULT351047	1 - Q-SUN	Sandblasted	Self-Adhered
ZULT351051	6 - Cyclic	Polished	Self-Adhered
ZULT351052	8 - Blow	Sandblasted	Self-Adhered
ZULT351054	10 - Wash	Sandblasted	Self-Adhered
ZULT351056	9 - Impact	Sandblasted	Self-Adhered
ZULT351057	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
ZULT351058	5 - Temperature	Sandblasted	Self-Adhered
ZULT351059	10 - Wash	Sandblasted	Self-Adhered
ZULT351062	7 - Corrosion (Fog)	Sandblasted	Self-Adhered
ZULT351064	5 - Temperature	Sandblasted	Self-Adhered
ZULT351065	10 - Wash	Sandblasted	Self-Adhered
ZULT351066	1 - Q-SUN	Polished	Self-Adhered
ZULT351067	9 - Impact	Sandblasted	Self-Adhered
ZULT351069	9 - Impact	Sandblasted	Self-Adhered
ZULT351070	4 - QUV & Q-FOG	Sandblasted	Self-Adhered
ZULT351071	4 - QUV & Q-FOG	Sandblasted	Self-Adhered
ZULT351073	5 - Temperature	Sandblasted	Self-Adhered
ZULT351076	8 - Blow	Sandblasted	Self-Adhered
ZULT351080	2 - QUV (UVA)	Polished	Self-Adhered
ZULT351085	9 - Impact	Sandblasted	Self-Adhered
ZULT351088	7 - Corrosion (Fog)	Sandblasted	Self-Adhered

Table B-7. 48 Zebra Z-Ultimate 3000T labels and associated environmental tests, continued.

Sample ID	Environmental Test	Coupon Finish	Attachment Method
ZULT351093	6 - Cyclic	Sandblasted	Self-Adhered
ZULT351095	3 - QUV (UVB)	Polished	Self-Adhered
ZULT351096	6 - Cyclic	Sandblasted	Self-Adhered
ZULT351097	3 - QUV (UVB)	Sandblasted	Self-Adhered
ZULT351098	1 - Q-SUN	Sandblasted	Self-Adhered
ZULT351099	10 - Wash	Sandblasted	Self-Adhered

APPENDIX C. BARCODE SAMPLES GROUPED BY ENVIRONMENTAL TESTS

APPENDIX C. BARCODE SAMPLES GROUPED BY ENVIRONMENTAL TESTS

Tables C-1 through C-10 indicate which samples were subjected to each of the 10 environmental tests. Provided for each sample is the test position, identification number, coupon finish, and attachment method.

Table C-1. 22 barcode samples subjected to Q-SUN xenon arc lamp testing (Test 1).

Test Position	Sample ID	Coupon Finish	Attachment Method
1	CERM123422	Polished	Aremco 517 Epoxy
2	CERM123446	Polished	Weld
3	ZULT351066	Polished	Self-Adhered
4	YAGL123457	Polished	Weld
5	ZEND451203	Sandblasted	Self-Adhered
6	ZULT351098	Sandblasted	Self-Adhered
7	REBO123455	Sandblasted	Self-Adhered
8	CERM123413	Free	Free
9	TESA123445	Polished	Self-Adhered
10	REBO123421	Polished	Self-Adhered
11	TESA123454	Sandblasted	Self-Adhered
12	CERM123495	Sandblasted	Aremco 517 Epoxy
13	TESA123465	Sandblasted	Self-Adhered
14	ETCH123416	Polished	Aremco 517 Epoxy
15	ETCH123480	Polished	Weld
16	YAGL123416	Sandblasted	Aremco 517 Epoxy
17	ZEND451213	Sandblasted	Self-Adhered
18	ZULT351047	Sandblasted	Self-Adhered
19	ETCH123438	Sandblasted	Aremco 517 Epoxy
20	YAGL123493	Polished	Aremco 517 Epoxy
21	ZEND451228	Polished	Self-Adhered
22	REBO123408	Sandblasted	Self-Adhered

Table C-2. 24 barcode samples subjected to QUV UVA testing (Test 2).

Test Position	Sample ID	Coupon Finish	Attachment Method
1	CERM123402	Polished	Weld
2	ETCH123430	Sandblasted	Aremco 517 Epoxy
3	REBO123466	Sandblasted	Self-Adhered
4	ZEND451211	Sandblasted	Self-Adhered
5	CERM123488	Sandblasted	Aremco 517 Epoxy
6	TESA123409	Sandblasted	Self-Adhered
7	ETCH123409	Polished	Aremco 517 Epoxy
8	CERM123432	Free	Free
9	TESA123425	Sandblasted	Self-Adhered
10	REBO123424	Polished	Self-Adhered
11	YAGL123459	Polished	Aremco 517 Epoxy
12	TESA123414	Polished	Self-Adhered
13	ZULT351037	Sandblasted	Self-Adhered
14	YAGL123460	Free	Free
15	ETCH123473	Polished	Weld
16	ZULT351080	Polished	Self-Adhered
17	CERM123460	Polished	Aremco 517 Epoxy
18	ZEND451204	Sandblasted	Self-Adhered
19	YAGL123488	Sandblasted	Aremco 517 Epoxy
20	ZULT351017	Sandblasted	Self-Adhered
21	ZEND451230	Polished	Self-Adhered
22	REBO123429	Sandblasted	Self-Adhered
23	YAGL123458	Polished	Weld
24	ETCH123422	Free	Free

Table C-3. 24 barcode samples subjected to QUV UVB testing (Test 3).

Test Position	Sample ID	Coupon Finish	Attachment Method
1	REBO123452	Sandblasted	Self-Adhered
2	CERM123436	Sandblasted	Aremco 517 Epoxy
3	ZEND451219	Sandblasted	Self-Adhered
4	CERM123465	Polished	Weld
5	ZULT351097	Sandblasted	Self-Adhered
6	YAGL123437	Polished	Weld
7	REBO123470	Polished	Self-Adhered
8	ETCH123497	Sandblasted	Aremco 517 Epoxy
9	ZEND451214	Polished	Self-Adhered
10	REBO123451	Sandblasted	Self-Adhered
11	YAGL123473	Sandblasted	Aremco 517 Epoxy
12	ETCH123493	Polished	Aremco 517 Epoxy
13	CERM123438	Free	Free
14	TESA123441	Sandblasted	Self-Adhered
15	YAGL123440	Polished	Aremco 517 Epoxy
16	ZEND451221	Sandblasted	Self-Adhered
17	ETCH123437	Polished	Self-Adhered
18	CERM123499	Polished	Aremco 517 Epoxy
19	ZULT351095	Polished	Self-Adhered
20	ZULT351040	Sandblasted	Self-Adhered
21	TESA123406	Sandblasted	Self-Adhered
22	YAGL123490	Free	Free
23	TESA123478	Polished	Self-Adhered
24	ETCH123407	Free	Free

Table C-4. 24 barcode samples subjected to QUV and Q-FOG testing (Test 4).

Test Position	Sample ID	Coupon Finish	Attachment Method
1	ZULT351070	Sandblasted	Self-Adhered
2	YAGL123499	Sandblasted	Aremco 517 Epoxy
3	ZEND451202	Polished	Self-Adhered
4	CERM123450	Polished	Aremco 517 Epoxy
5	ZEND451220	Sandblasted	Self-Adhered
6	ETCH123406	Sandblasted	Aremco 517 Epoxy
7	REBO123442	Sandblasted	Self-Adhered
8	ETCH123412	Free	Free
9	CERM123425	Sandblasted	Aremco 517 Epoxy
10	TESA123420	Sandblasted	Self-Adhered
11	ZEND451201	Sandblasted	Self-Adhered
12	ZULT351042	Polished	Self-Adhered
13	TESA123470	Polished	Self-Adhered
14	REBO123427	Polished	Self-Adhered
15	YAGL123461	Free	Free
16	YAGL123462	Polished	Aremco 517 Epoxy
17	ETCH123431	Polished	Weld
18	REBO123456	Sandblasted	Self-Adhered
19	CERM123441	Free	Free
20	ZULT351071	Sandblasted	Self-Adhered
21	TESA123415	Sandblasted	Self-Adhered
22	YAGL123412	Polished	Weld
23	ETCH123402	Polished	Aremco 517 Epoxy
24	CERM123414	Polished	Weld

Table C-5. 61 barcode samples subjected to temperature testing (Test 5).

Test Position	Sample ID	Coupon Finish	Attachment Method
1	ZEND451226	Polished	Self-Adhered
2	ETCH123454	Sandblasted	Aremco 517 Epoxy
3	ETCH123415	Free	Free
4	TESA123421	Polished	Self-Adhered
5	YAGL123480	Sandblasted	Aremco 517 Epoxy
6	CERM123478	Polished	Weld
7	REBO123463	Sandblasted	Self-Adhered
8	ZULT351009	Sandblasted	Self-Adhered
9	YAGL123402	Free	Free
10	YAGL123418	Free	Free
11	ZULT351073	Sandblasted	Self-Adhered
12	ETCH123481	Free	Free
13	ETCH123477	Polished	Weld
14	CERM123444	Polished	Aremco 517 Epoxy
15	ZULT351058	Sandblasted	Self-Adhered
16	YAGL123463	Free	Free
17	CERM123426	Free	Free
18	REBO123490	Polished	Self-Adhered
19	REBO123467	Sandblasted	Self-Adhered
20	ETCH123405	Free	Free
21	CERM123468	Free	Free
22	TESA123473	Sandblasted	Self-Adhered
23	TESA123460	Sandblasted	Self-Adhered
24	CERM123481	Polished	Aremco 517 Epoxy
25	REBO123457	Sandblasted	Self-Adhered
26	YAGL123432	Sandblasted	Aremco 517 Epoxy
27	TESA123438	Sandblasted	Self-Adhered
28	YAGL123434	Free	Free
29	ZULT351064	Sandblasted	Self-Adhered
30	YAGL123425	Sandblasted	Aremco 517 Epoxy
31	ZEND451222	Sandblasted	Self-Adhered
32	ETCH123483	Sandblasted	Aremco 517 Epoxy
33	ETCH123485	Polished	Aremco 517 Epoxy
34	REBO123477	Sandblasted	Self-Adhered
35	YAGL123450	Free	Free
36	ZEND451227	Sandblasted	Self-Adhered
37	CERM123421	Sandblasted	Aremco 517 Epoxy
38	CERM123498	Sandblasted	Aremco 517 Epoxy
39	CERM123417	Free	Free
40	REBO123412	Sandblasted	Self-Adhered
41	CERM123434	Sandblasted	Aremco 517 Epoxy
42	TESA123462	Sandblasted	Self-Adhered

Table C-5. 61 barcode samples subjected to temperature testing (Test 5), continued.

Test Position	Sample ID	Coupon Finish	Attachment Method
43	CERM123404	Sandblasted	Aremco 517 Epoxy
44	ZULT351036	Polished	Self-Adhered
45	CERM123484	Free	Free
46	ETCH123472	Free	Free
47	ZULT351006	Sandblasted	Self-Adhered
48	CERM123400	Free	Free
49	ETCH123426	Sandblasted	Aremco 517 Epoxy
50	ETCH123498	Sandblasted	Aremco 517 Epoxy
51	ZEND451212	Sandblasted	Self-Adhered
52	ETCH123499	Sandblasted	Aremco 517 Epoxy
53	YAGL123424	Polished	Aremco 517 Epoxy
54	ZEND451225	Sandblasted	Self-Adhered
55	ETCH123446	Free	Free
56	ZEND451217	Sandblasted	Self-Adhered
57	TESA123463	Sandblasted	Self-Adhered
58	YAGL123409	Polished	Weld
59	CERM123490	Sandblasted	Aremco 517 Epoxy
60	YAGL123475	Sandblasted	Aremco 517 Epoxy
61	YAGL123464	Sandblasted	Aremco 517 Epoxy

Table C-6. 63 barcode samples subjected to cyclic corrosion testing (Test 6).

Test Position	Sample ID	Coupon Finish	Attachment Method
1	ETCH123434	Sandblasted	Aremco 517 Epoxy
2	CERM123459	Free	Free
3	ZULT351093	Sandblasted	Self-Adhered
4	TESA123429	Polished	Self-Adhered
5	REBO123441	Sandblasted	Self-Adhered
6	CERM123411	Sandblasted	Aremco 517 Epoxy
7	ETCH123478	Polished	Weld
8	TESA123456	Sandblasted	Self-Adhered
9	YAGL123478	Free	Free
10	YAGL123453	Polished	Weld
11	ZULT351015	Sandblasted	Self-Adhered
12	YAGL123468	Free	Free
13	CERM123496	Free	Free
14	YAGL123430	Free	Free
15	ZULT351043	Sandblasted	Self-Adhered
16	YAGL123497	Polished	Weld
17	ETCH123469	Sandblasted	Aremco 517 Epoxy
18	YAGL123470	Sandblasted	Aremco 517 Epoxy
19	ZULT351051	Polished	Self-Adhered
20	REBO123448	Sandblasted	Self-Adhered
21	YAGL123491	Sandblasted	Aremco 517 Epoxy
22	ETCH123436	Polished	Weld
23	CERM123405	Free	Free
24	TESA123402	Sandblasted	Self-Adhered
25	CERM123452	Polished	Weld
26	YAGL123474	Sandblasted	Aremco 517 Epoxy
27	ETCH123494	Sandblasted	Aremco 517 Epoxy
28	YAGL123477	Polished	Aremco 517 Epoxy
29	YAGL123467	Free	Free
30	ETCH123420	Sandblasted	Aremco 517 Epoxy
31	CERM123473	Sandblasted	Aremco 517 Epoxy
32	CERM123431	Sandblasted	Aremco 517 Epoxy
33	CERM123454	Polished	Weld
34	TESA123430	Sandblasted	Self-Adhered
35	ZEND451231	Sandblasted	Self-Adhered
36	CERM123475	Sandblasted	Aremco 517 Epoxy
37	CERM123423	Free	Free
38	YAGL123482	Free	Free
39	ZEND451205	Sandblasted	Self-Adhered
40	ZULT351038	Sandblasted	Self-Adhered
41	ETCH123448	Polished	Aremco 517 Epoxy
42	ETCH123464	Free	Free

Table C-6. 63 barcode samples subjected to cyclic corrosion testing (Test 6), continued.

Test Position	Sample ID	Coupon Finish	Attachment Method
43	CERM123448	Sandblasted	Aremco 517 Epoxy
44	ETCH123414	Free	Free
45	REBO123402	Polished	Self-Adhered
46	REBO123416	Sandblasted	Self-Adhered
47	TESA123431	Sandblasted	Self-Adhered
48	TESA123491	Sandblasted	Self-Adhered
49	YAGL123489	Sandblasted	Aremco 517 Epoxy
50	CERM123491	Sandblasted	Aremco 517 Epoxy
51	CERM123419	Polished	Aremco 517 Epoxy
52	ETCH123450	Free	Free
53	ETCH123491	Free	Free
54	YAGL123415	Sandblasted	Aremco 517 Epoxy
55	CERM123494	Free	Free
56	REBO123418	Sandblasted	Self-Adhered
57	YAGL123498	Free	Free
58	ETCH123410	Sandblasted	Aremco 517 Epoxy
59	REBO123415	Sandblasted	Self-Adhered
60	ETCH123427	Free	Free
61	ZEND451209	Sandblasted	Self-Adhered
62	ZEND451215	Polished	Self-Adhered
63	ZULT351096	Sandblasted	Self-Adhered

Table C-7. 57 barcode samples subjected to corrosion testing (Test 7).

Test Position	Sample ID	Coupon Finish	Attachment Method
1	REBO123453	Sandblasted	Self-Adhered
2	ZEND451232	Sandblasted	Self-Adhered
3	TESA123472	Sandblasted	Self-Adhered
4	ZULT351034	Sandblasted	Self-Adhered
5	TESA123444	Sandblasted	Self-Adhered
6	ZULT351062	Sandblasted	Self-Adhered
7	CERM123462	Free	Free
8	ZULT351003	Sandblasted	Self-Adhered
9	YAGL123472	Free	Free
10	YAGL123408	Sandblasted	Aremco 517 Epoxy
11	CERM123412	Free	Free
12	YAGL123476	Polished	Weld
13	YAGL123427	Free	Free
14	YAGL123486	Sandblasted	Aremco 517 Epoxy
15	YAGL123481	Polished	Weld
16	ETCH123411	Sandblasted	Aremco 517 Epoxy
17	ETCH123458	Polished	Weld
18	TESA123437	Sandblasted	Self-Adhered
19	ZEND451207	Sandblasted	Self-Adhered
20	YAGL123456	Free	Free
21	CERM123497	Sandblasted	Aremco 517 Epoxy
22	ZULT351057	Sandblasted	Self-Adhered
23	ETCH123423	Sandblasted	Aremco 517 Epoxy
24	REBO123428	Sandblasted	Self-Adhered
25	TESA123498	Sandblasted	Self-Adhered
26	CERM123457	Sandblasted	Aremco 517 Epoxy
27	TESA123433	Sandblasted	Self-Adhered
28	ETCH123417	Free	Free
29	ZULT351088	Sandblasted	Self-Adhered
30	CERM123480	Polished	Weld
31	CERM123483	Free	Free
32	ETCH123443	Sandblasted	Aremco 517 Epoxy
33	TESA123486	Sandblasted	Self-Adhered
34	REBO123425	Sandblasted	Self-Adhered
35	YAGL123439	Free	Free
36	CERM123420	Free	Free
37	CERM123403	Free	Free
38	ETCH123495	Free	Free
39	REBO123494	Sandblasted	Self-Adhered
40	YAGL123447	Sandblasted	Aremco 517 Epoxy
41	YAGL123496	Sandblasted	Aremco 517 Epoxy
42	CERM123449	Sandblasted	Aremco 517 Epoxy

Table C-7. 57 barcode samples subjected to corrosion testing (Test 7), continued.

Test Position	Sample ID	Coupon Finish	Attachment Method
43	CERM123406	Sandblasted	Aremco 517 Epoxy
44	YAGL123403	Free	Free
45	ETCH123421	Free	Free
46	ZEND451007	Sandblasted	Self-Adhered
47	ETCH123476	Free	Free
48	ETCH123445	Polished	Weld
49	ETCH123484	Free	Free
50	CERM123471	Polished	Weld
51	REBO123413	Sandblasted	Self-Adhered
52	ETCH123425	Sandblasted	Aremco 517 Epoxy
53	ETCH123471	Sandblasted	Aremco 517 Epoxy
54	YAGL123455	Free	Free
55	REBO123492	Sandblasted	Self-Adhered
56	ZULT351014	Sandblasted	Self-Adhered
57	YAGL123448	Sandblasted	Aremco 517 Epoxy

Table C-8. 57 barcode samples subjected to blowing sand/dust testing (Test 8).

Test Position	Sample ID	Coupon Finish	Attachment Method
1	ETCH123408	Sandblasted	Aremco 517 Epoxy
2	CERM123487	Free	Free
3	YAGL123426	Sandblasted	Aremco 517 Epoxy
4	YAGL123465	Free	Free
5	CERM123410	Sandblasted	Aremco 517 Epoxy
6	CERM123409	Free	Free
7	ETCH123442	Sandblasted	Aremco 517 Epoxy
8	TESA123468	Sandblasted	Self-Adhered
9	ZULT351041	Sandblasted	Aremco 517 Epoxy
10	YAGL123405	Sandblasted	Aremco 517 Epoxy
11	REBO123430	Sandblasted	Self-Adhered
12	YAGL123401	Free	Free
13	ZULT351012	Sandblasted	Self-Adhered
14	REBO123482	Sandblasted	Self-Adhered
15	ETCH123460	Free	Free
16	YAGL123442	Free	Free
17	YAGL123444	Free	Free
18	ETCH123490	Free	Free
19	CERM123476	Polished	Weld
20	REBO123471	Sandblasted	Self-Adhered
21	ETCH123496	Free	Free
22	ETCH123492	Polished	Weld
23	YAGL123452	Free	Free
24	TESA123422	Sandblasted	Self-Adhered
25	ZEND451008	Sandblasted	Self-Adhered
26	ETCH123419	Free	Free
27	CERM123447	Free	Free
28	ETCH123489	Sandblasted	Aremco 517 Epoxy
29	CERM123418	Free	Free
30	YAGL123492	Free	Free
31	ZEND451208	Sandblasted	Self-Adhered
32	TESA123457	Sandblasted	Self-Adhered
33	ZULT351035	Sandblasted	Self-Adhered
34	YAGL123433	Sandblasted	Aremco 517 Epoxy
35	ETCH123479	Sandblasted	Aremco 517 Epoxy
36	CERM123433	Sandblasted	Aremco 517 Epoxy
37	YAGL123420	Sandblasted	Aremco 517 Epoxy
38	ETCH123475	Sandblasted	Aremco 517 Epoxy
39	ZULT351052	Sandblasted	Self-Adhered
40	CERM123469	Sandblasted	Aremco 517 Epoxy
41	ZULT351023	Sandblasted	Self-Adhered
42	YAGL123414	Polished	Weld

Table C-8. 57 barcode samples subjected to blowing sand/dust testing (Test 8), continued.

Test Position	Sample ID	Coupon Finish	Attachment Method
43	ETCH123457	Free	Free
44	REBO123479	Sandblasted	Self-Adhered
45	REBO123433	Sandblasted	Self-Adhered
46	YAGL123407	Sandblasted	Aremco 517 Epoxy
47	YAGL123484	Polished	Weld
48	CERM123424	Sandblasted	Aremco 517 Epoxy
49	ETCH123413	Polished	Weld
50	TESA123469	Sandblasted	Self-Adhered
51	CERM123435	Free	Free
52	ZULT351076	Sandblasted	Self-Adhered
53	ZEND451233	Sandblasted	Self-Adhered
54	REBO123496	Sandblasted	Self-Adhered
55	TESA123427	Sandblasted	Self-Adhered
56	CERM123464	Polished	Weld
57	TESA123475	Sandblasted	Self-Adhered

Table C-9. 55 barcode samples subjected to impact testing (Test 9).

Test Position	Sample ID	Coupon Finish	Attachment Method
1	YAGL123469	Free	Free
2	CERM123407	Free	Free
3	TESA123407	Sandblasted	Self-Adhered
4	ZULT351056	Sandblasted	Self-Adhered
5	ETCH123439	Sandblasted	Aremco 517 Epoxy
6	TESA123483	Sandblasted	Self-Adhered
7	YAGL123400	Sandblasted	Aremco 517 Epoxy
8	ETCH123487	Sandblasted	Aremco 517 Epoxy
9	CERM123489	Free	Free
10	YAGL123479	Free	Free
11	ZULT351039	Sandblasted	Self-Adhered
12	ETCH123463	Free	Free
13	CERM123492	Free	Free
14	REBO123454	Sandblasted	Self-Adhered
15	ZEND451210	Sandblasted	Self-Adhered
16	REBO123450	Sandblasted	Self-Adhered
17	YAGL123445	Sandblasted	Aremco 517 Epoxy
18	CERM123479	Sandblasted	Aremco 517 Epoxy
19	CERM123440	Sandblasted	Aremco 517 Epoxy
20	TESA123412	Sandblasted	Self-Adhered
21	ETCH123429	Free	Free
22	REBO123476	Sandblasted	Self-Adhered
23	TESA123442	Sandblasted	Self-Adhered
24	TESA123494	Sandblasted	Self-Adhered
25	ETCH123466	Polished	Weld
26	TESA123418	Sandblasted	Self-Adhered
27	YAGL123435	Polished	Weld
28	YAGL123410	Sandblasted	Aremco 517 Epoxy
29	ZEND451216	Sandblasted	Self-Adhered
30	ETCH123403	Sandblasted	Aremco 517 Epoxy
31	CERM123428	Free	Free
32	REBO123462	Sandblasted	Self-Adhered
33	CERM123485	Polished	Weld
34	CERM123466	Sandblasted	Aremco 517 Epoxy
35	ZULT351069	Sandblasted	Self-Adhered
36	YAGL123446	Polished	Weld
37	YAGL123411	Free	Free
38	YAGL123419	Free	Free
39	ETCH123470	Free	Free
40	CERM123458	Free	Free
41	ZULT351085	Sandblasted	Self-Adhered
42	ZULT351067	Sandblasted	Self-Adhered

Table C-9. 55 barcode samples subjected to impact testing (Test 9), continued.

Test Position	Sample ID	Coupon Finish	Attachment Method
43	REBO123420	Sandblasted	Self-Adhered
44	ZULT351007	Sandblasted	Self-Adhered
45	ETCH123401	Free	Free
46	CERM123493	Polished	Weld
47	YAGL123441	Free	Free
48	REBO123468	Sandblasted	Self-Adhered
49	ZEND451218	Sandblasted	Self-Adhered
50	ETCH123400	Polished	Weld
51	YAGL123483	Free	Free
52	ETCH123441	Sandblasted	Aremco 517 Epoxy
53	YAGL123422	Sandblasted	Aremco 517 Epoxy
54	ETCH123424	Free	Free
55	CERM123482	Sandblasted	Aremco 517 Epoxy

Table C-10. 57 barcode samples subjected to high pressure and temperature water jet (Test 10).

Test Position	Sample ID	Coupon Finish	Attachment Method
1	ZULT351016	Sandblasted	Self-Adhered
2	REBO123474	Sandblasted	Self-Adhered
3	CERM123472	Sandblasted	Aremco 517 Epoxy
4	REBO123411	Sandblasted	Self-Adhered
5	YAGL123449	Free	Free
6	ETCH123447	Free	Free
7	ZULT351059	Sandblasted	Self-Adhered
8	REBO123439	Sandblasted	Self-Adhered
9	ZULT351099	Sandblasted	Self-Adhered
10	ZEND451223	Sandblasted	Self-Adhered
11	YAGL123428	Free	Free
12	ETCH123444	Free	Free
13	TESA123423	Sandblasted	Self-Adhered
14	CERM123427	Free	Free
15	ETCH123482	Sandblasted	Aremco 517 Epoxy
16	ETCH123461	Free	Free
17	ZULT351065	Sandblasted	Self-Adhered
18	CERM123430	Sandblasted	Aremco 517 Epoxy
19	TESA123411	Sandblasted	Self-Adhered
20	ETCH123474	Sandblasted	Aremco 517 Epoxy
21	CERM123470	Polished	Weld
22	ZEND451206	Sandblasted	Self-Adhered
23	ETCH123452	Free	Free
24	CERM123401	Free	Free
25	TESA123449	Sandblasted	Self-Adhered
26	CERM123461	Polished	Weld
27	ETCH123404	Sandblasted	Aremco 517 Epoxy
28	CERM123416	Sandblasted	Aremco 517 Epoxy
29	ZULT351013	Sandblasted	Self-Adhered
30	ETCH123451	Free	Free
31	CERM123445	Free	Free
32	ETCH123449	Sandblasted	Aremco 517 Epoxy
33	TESA123493	Sandblasted	Self-Adhered
34	ETCH123467	Polished	Weld
35	REBO123436	Sandblasted	Self-Adhered
36	ETCH123459	Polished	Weld
37	TESA123410	Sandblasted	Self-Adhered
38	YAGL123443	Free	Free
39	ZEND451224	Sandblasted	Self-Adhered
40	REBO123444	Sandblasted	Self-Adhered
41	ZULT351054	Sandblasted	Self-Adhered
42	YAGL123485	Sandblasted	Aremco 517 Epoxy

Table C-10. 57 barcode samples subjected to high pressure and temperature water jet (Test 10), continued.

Test Position	Sample ID	Coupon Finish	Attachment Method
43	ETCH123468	Sandblasted	Aremco 517 Epoxy
44	YAGL123417	Free	Free
45	YAGL123494	Sandblasted	Aremco 517 Epoxy
46	YAGL123451	Polished	Weld
47	YAGL123471	Sandblasted	Aremco 517 Epoxy
48	YAGL123429	Sandblasted	Aremco 517 Epoxy
49	YAGL123406	Free	Free
50	YAGL123423	Sandblasted	Aremco 517 Epoxy
51	TESA123488	Sandblasted	Self-Adhered
52	CERM123467	Free	Free
53	CERM123451	Sandblasted	Aremco 517 Epoxy
54	YAGL123466	Free	Free
55	REBO123495	Sandblasted	Self-Adhered
56	YAGL123495	Polished	Weld
57	CERM123443	Free	Free