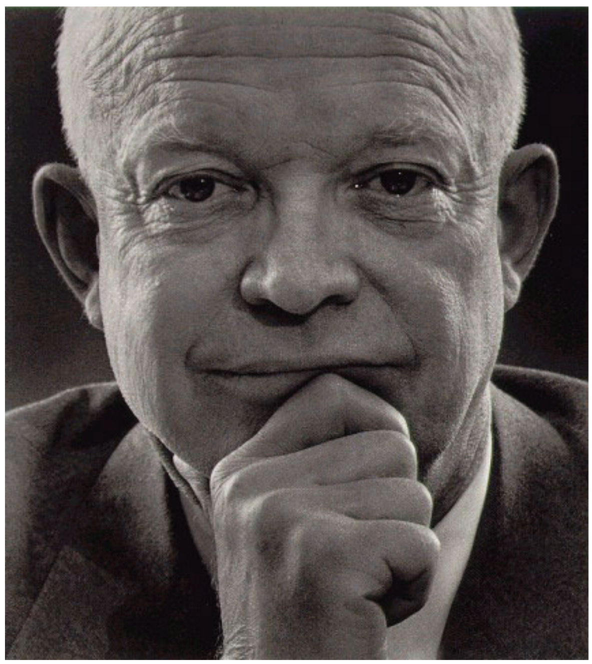
EISENHOWER MEMORIAL
TAPESTRY ENGINEERING
AND TECHNICAL DATA SUMMARY

VOLUME 2: TAPESTRY TECHNICAL DATA SUMMARY



NATIONAL CAPITAL PLANNING COMMISSION

SUBMISSION FOR PRELIMINARY DESIGN REVIEW
SUBMISSION DATE: FEBRUARY 5, 2014
MEETING DATE: APRIL 3, 2014

Gehry Partners, LLP ● **AECOM** Joint Venture

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EISENHOWER MEMORIAL
TAPESTRY ENGINEERING
AND TESTING DATA SUMMARY

VOLUME 2: TAPESTRY OVERVIEW AND TESTING DATA SUMMARY

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EISENHOWER MEMORIAL
TAPESTRY ENGINEERING AND TECHNICAL DATA SUMMARY

VOLUME 2 - TAPESTRY TECHNICAL DATA SUMMARY

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4.0 TAPESTRY MATERIAL TESTING

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4.1 TWISTED AND BRAIDED WIRE PROPERTIES

This section contains the Material Certifications for the twisted and braided wires utilized in the in the Environmental Corrosion Testing in Section 4.3 and Mechanical Tension and Shear Strength Analysis in Section 4.4.

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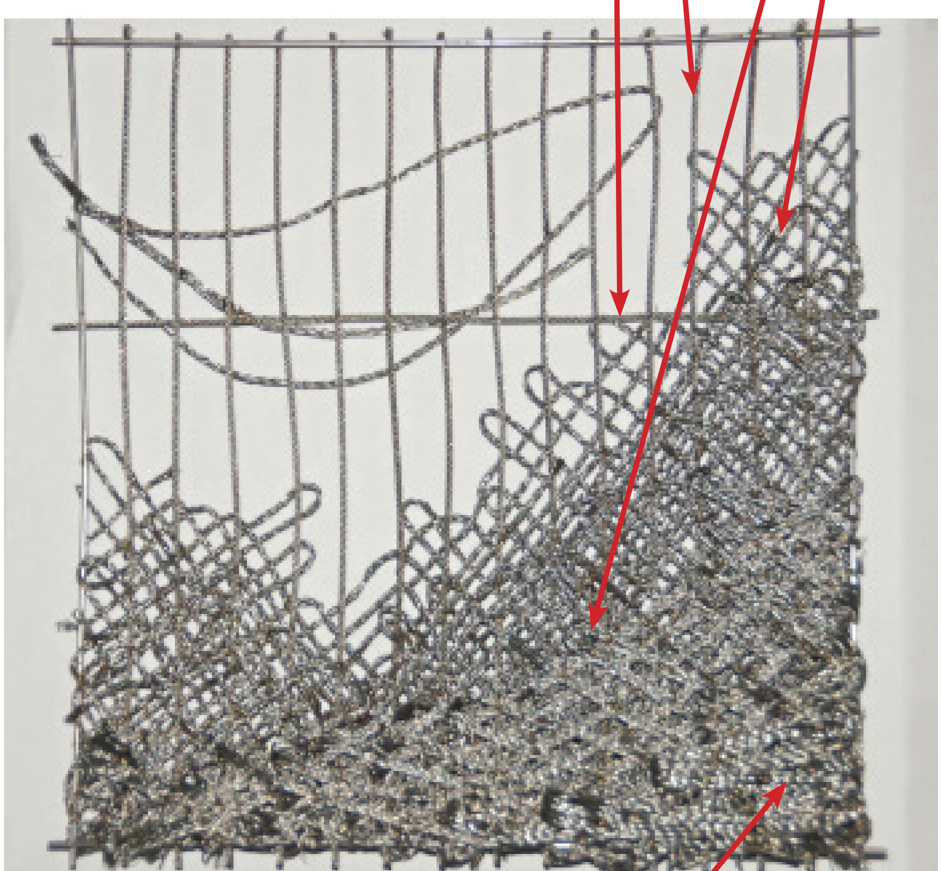
TAPESTRY TWISTED AND BRAIDED WIRE PANEL CONSTRUCTION

STRUCTURAL PANEL VERTICAL WIRE TYPE - 7x7 TWISTED STAINLESS STEEL WIRE 1/16” DIAMETER

STRUCTURAL PANEL HORIZONTAL WIRE TYPE 7x7 TWISTED STAINLESS STEEL WIRE 1/16” DIAMETER

ART BRAIDED WIRE - 1-16 BRAIDED WIRE STAINLESS STEEL 1/16” DIAMETER (IMAGE LAYER ON BOTH SIDES)

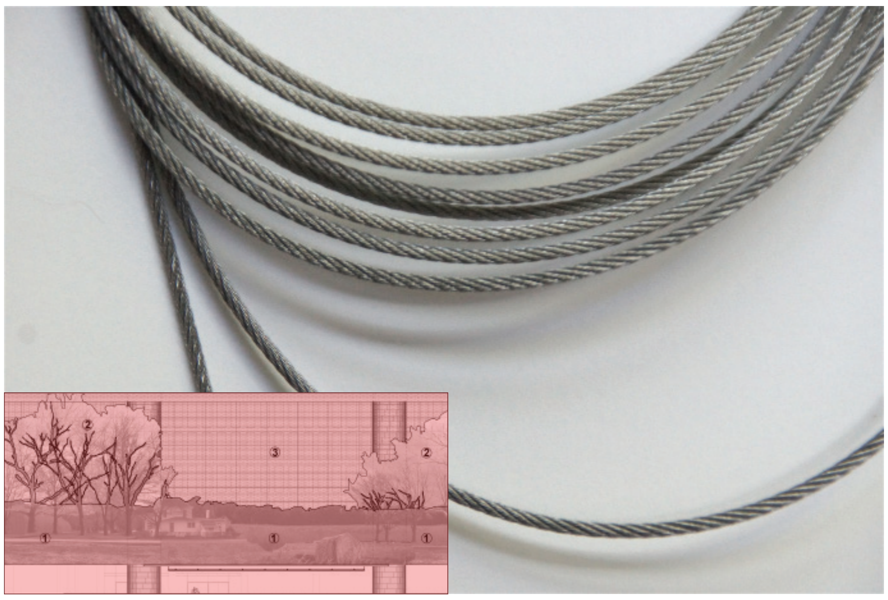
ART BRAIDED WIRE - 1-24 BRAIDED WIRE STAINLESS STEEL 3/32” DIAMETER (IMAGE LAYER ON BOTH SIDES)



ART BRAIDED WIRE - 2-24 STRAND BRAIDED WIRE STAINLESS STEEL 1/8” DIAMETER (ON BOTH SIDES OF IMAGE LAYER)

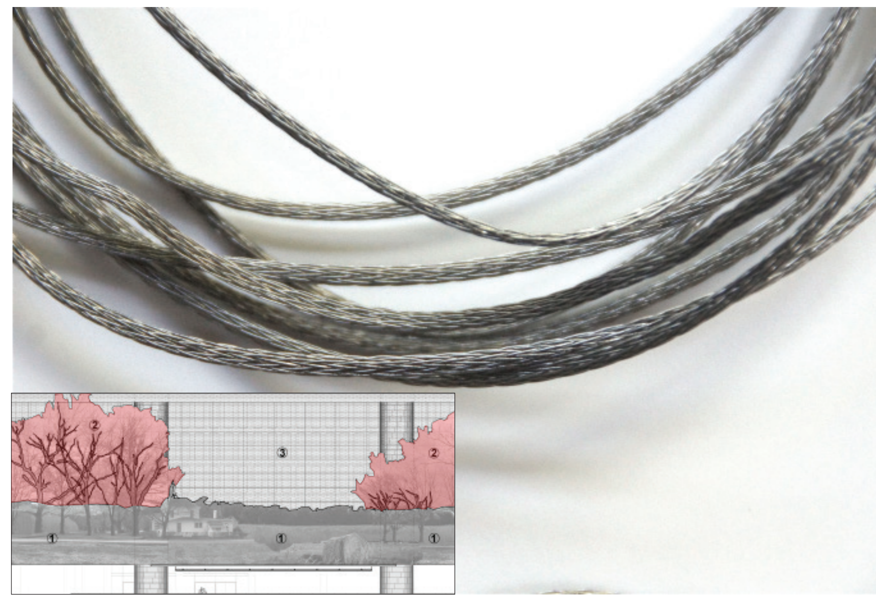
TAPESTRY TWISTED AND BRAIDED WIRE TYPES

STRUCTURAL PANEL HORIZONTAL AND VERTICAL WIRE TYPE



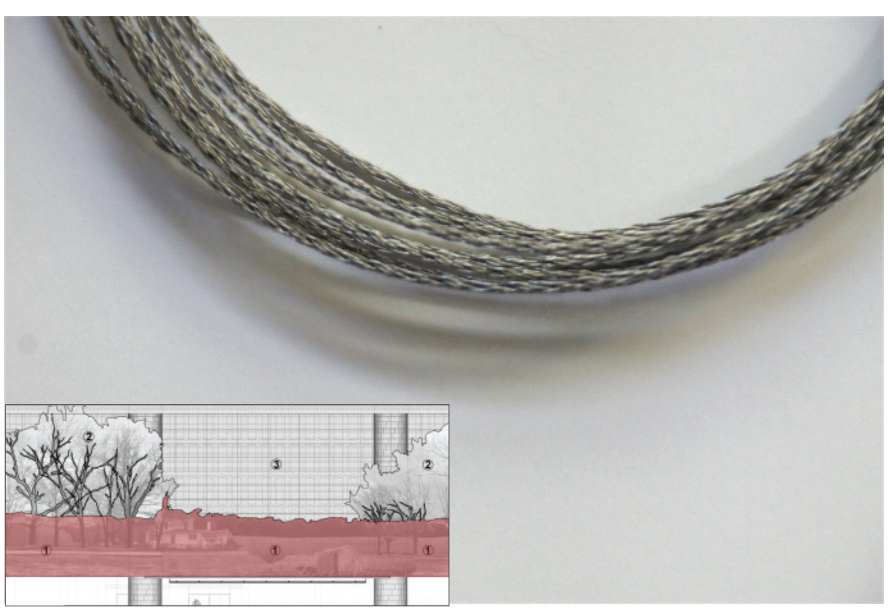
7X7 TWISTED STAINLESS STEEL CABLE
1/16" DIAMETER

ART WIRE TYPE



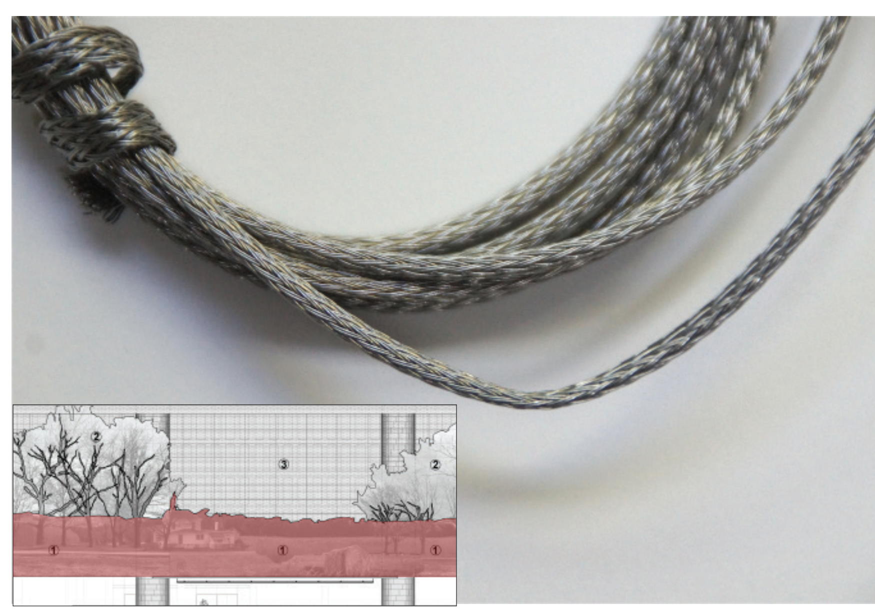
1-24 BRAIDED WIRE STAINLESS STEEL
1/16" DIAMETER

ART WIRE TYPE



1-16 BRAIDED WIRE STAINLESS STEEL
1/16" DIAMETER

ART WIRE TYPE



2-24 STRAND BRAIDED WIRE STAINLESS STEEL
1/8" DIAMETER

TWISTED AND BRAIDED WIRE PROPERTIES

See Section 5.1 Twisted and Braided Wire Environmental Corrosion Test - These twisted and braided wires are representative of the tapestry fabrication wire type. Alloy 317L is the selected alloy for the Tapestry fabrication and Alloy 316L samples are provided for reference information only.

Wire	Average Diameter	ASTM	Tensile Breaking Value (LBS)
STRUCTURAL TWISTED WIRE TYPES			
1/16" 7x7 SS T-317L Annealed Reel # U37889, U37890, U37891	0.0625"	ASTM E8	Tested load pending
1/16" 7x7 SS T-316L Annealed Reel # T19100, T19101	0.0625"	ASTM E8	463
ART BRAIDED WIRE TYPES			
16x1x30 SS Braid T-316L Reel #: T08548	0.0673"	ASTM E8	158.6
16x1x30 SS Braid T-316L Reel #: T08550	0.0652"	ASTM E8	158.5
24x1x30 SS Braid T-316L Reel #: T07271	0.0902"	ASTM E8	229
24x1x30 SS Braid T-316L Reel #: T07272	0.0901"	ASTM E8	228
24x2x30 SS Braid T-316L Reel #: T07267, # T07268	0.1485"	ASTM E8	462
24x2x30 SS Braid T-316L Reel #: T07269, #T07270	0.1478"	ASTM E8	463

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TWISTED STRUCTURAL WIRE
USED IN TEST SAMPLES #1 - 44
Included in Section 4.3 Element Report # TOM002-21955 CORROSION and
Section 4.4 Element Report #TOM002-21955M

ALLOY FOR TAPESTRY CONSTRUCTION

MATERIAL CERTIFICATION

TOMAS OSINSKI DESIGN, INC — December 19, 2013

PO #: 92413-TOM

Item #: 642-0627-7X7

Description: 1/16” 7X7 T-317L SS ANNEALED

Lot Size: 10,800 FT

- REEL # U37889 - 2,500 FT (18.95 LBS NET)
- REEL # U37890 - 4,000 FT (31.11 LBS NET)
- REEL # U37891 - 4,300 FT (32.30 LBS NET)

Material: STAINLESS STEEL

Type: T-317L

CHEMICAL ANALYSIS				
Heat #	**C**	**Cr**	**Mn**	**Mo**
112035	0.0100	18.9540	1.5940	3.5830
N	**Ni**	**P**	**S**	**Si**
0.0420	14.6240	0.0143	0.0006	0.3630

MADE IN U.S.A.

TWISTED STRUCTURAL WIRE
USED IN TEST SAMPLES #51 - 94 and #101-144
Included in Section 4.3 Element Report # TOM002-21955 CORROSION and
Section 4.4 Element Report #TOM002-21955M

FOR REFERENCE ONLY

MATERIAL CERTIFICATION

January 28, 2013

PO #: 121212-TOM

Item #: 642-0625-7X7
Description: 1/16” 7X7 SS T-316L ANNEALED
Lot Size: 10,200 FT
Reels: 2
Reel 1 #T19100 5,000 FT
Reel 2 #T19101 5,200 FT

Material: STAINLESS STEEL
Type: 316L

CHEMICAL ANALYSIS				
Heat #	**Al**	**As**	**B**	**C**
E120079	0.007	0.001	0.0004	0.018
Ca	**Co**	**Cr**	**Cu**	**Mn**
0.001	0.237	16.83	0.346	0.85
Mo	**N**	**Nb**	**Ni**	**P**
2.04	0.041	0.015	11.11	0.028
Pb	**S**	**Si**	**Sn**	**Ta**
0.0003	0.003	0.515	0.007	0.002
Ti	**V**	**W**		
0.019	0.08	0.07		

MADE IN U.S.A.

BRAIDED ART WIRE
USED IN TEST SAMPLES #101-144 and #151-194
Included in Section 4.3 Element Report # TOM002-21955 CORROSION and
Section 4.4 Element Report #TOM002-21955M

FOR REFERENCE ONLY

MATERIAL CERTIFICATION

January 3, 2013

PO #: 112612-TOM

Item #: 028-1613-316L
Description: 16x1x30 SS BRAID T-316L
Lot Size: 10,206 FT
Reels: 2

Material: STAINLESS STEEL
Type: 316L

PHYSICAL						
Reel #	**Avg Diam**	**Break**		**Reel #**	**Avg Diam**	**Break**
T08548	0.0673”	158.6 LBS				
T08550	0.0652”	158.5 LBS				

CHEMICAL ANALYSIS				
Heat #	**C**	**Cr**	**Cu**	**Mn**
512435	0.022	16.29	0.1	0.63
Mo	**Ni**	**P**	**S**	**Si**
2.03	10.01	0.031	0.001	0.41

MADE IN U.S.A.

TWISTED STRUCTURAL WIRE
USED IN TEST SAMPLES #151 - 194 and #201-244
Included in Section 4.3 Element Report # TOM002-21955 CORROSION and Section 4.4 Element Report #TOM002-21955M

FOR REFERENCE ONLY

MATERIAL CERTIFICATION

January 3, 2013

PO #: 112612-TOM

Item #: 028-2413-316L
Description: 24x1x30 SS BRAID T-316L
Lot Size: 10,274 FT
Reels: 2

Material: STAINLESS STEEL
Type: 316L

PHYSICAL						
Reel #	**Avg Diam**	**Break**		**Reel #**	**Avg Diam**	**Break**
T07271	0.0902”	229 LBS				
T07272	0.0901”	228 LBS				

CHEMICAL ANALYSIS				
Heat #	**C**	**Cr**	**Cu**	**Mn**
512435	0.022	16.29	0.1	0.63
Mo	**Ni**	**P**	**S**	**Si**
2.03	10.01	0.031	0.001	0.41

CHEMICAL ANALYSIS				
Heat #	**C**	**Cr**	**Mn**	**Mo**
608018	0.022	16.78	0.94	2.02
N	**Ni**	**P**	**S**	**Si**
0.035	11.06	0.34	0.001	0.53

MADE IN U.S.A.

BRAIDED ART WIRE
USED IN TEST SAMPLES #201 - 244
Included in Section 4.3 Element Report # TOM002-21955 CORROSION and
Section 4.4 Element Report #TOM002-21955M

FOR REFERENCE ONLY

MATERIAL CERTIFICATION

January 3, 2013

PO #: 112612-TOM

Item #: 028-2423-316L
Description: 24x2x30 SS BRAID T-316L
Lot Size: 10,926 FT
Reels: 8

Material: STAINLESS STEEL
Type: 316L

PHYSICAL						
Reel #	**Avg Diam**	**Break**		**Reel #**	**Avg Diam**	**Break**
T07267	0.1485”	464 LBS		T07929	0.1464”	462 LBS
T07268	0.1485”	464 LBS		T07930	0.1464”	462 LBS
T07269	0.1478”	464 LBS		T07931	0.1445”	463 LBS
T07270	0.1478”	464 LBS		T07932	0.1445”	463 LBS

CHEMICAL ANALYSIS				
Heat #	**C**	**Cr**	**Cu**	**Mn**
512435	0.022	16.29	0.1	0.63
Mo	**Ni**	**P**	**S**	**Si**
2.03	10.01	0.031	0.001	0.41

MADE IN U.S.A.

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4.2 WELD STRENGTH AND ENVIRONMENTAL SAMPLE MATRIX

This section contains the Weld Strength and Environmental Corrosion Sample Matrix for reference. This matrix indicates the sample number, the specific properties of the sample, and the test procedures for each sample. The Environmental Corrosion Reports in Section 4.3 and the Mechanical Tension and Shear Strength Analysis in Section 4.4 utilize the sample numbering system in this matrix.

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Eisenhower Memorial
Tapestry Engineering and Data Summary
February 5, 2014

NCPC Preliminary Review

Weld Joint Strength Testing Sample Matrix - Executive Summary

Alloy	Mechanical Weld Strength Samples	Joint Type 1 # of samples 7X7 Twisted Wire to 7x7 Twisted Wire	Joint Type 2 # of samples 1-16 Braided Wire to 7x7 Twisted Wire	Joint Type 3 # of samples 1-16 Braided Wire to 1-24 Braided Wire	Joint Type 4 # of samples 1-24 Braided Wire to 2-24 Braided Wire	Notes
317L ANNEALED ALLOY REPRESENTATIVE SAMPLES FOR PROJECT	SAMPLES FOR MECHANICAL STRENGTH TESTING WITHOUT ENVIRONMENTAL CORROSION EXPOSURE					
	Shear Strength	6	Test For Final NCPC Review	Test For Final NCPC Review	Test For Final NCPC Review	Strength established from Average of 5 samples. One Sample for NIST
	Peel Strength	6	Test For Final NCPC Review	Test For Final NCPC Review	Test For Final NCPC Review	Strength established from Average of 5 samples. One Sample for NIST
	Torque Shear Strength	6	Test For Final NCPC Review	Test For Final NCPC Review	Test For Final NCPC Review	Strength established from Average of 5 samples. One Sample for NIST
	SAMPLES FOR MECHANICAL WELD STRENGTH WITH ENVIRONMENTAL CORROSION EXPOSURE					
	Shear Strength	6	Test for Final NCPC Review	Test for Final NCPC Review	Test for Final NCPC Review	Strength established from Average of 5 samples. One Sample for NIST
	Peel Strength	6	Test for Final NCPC Review	Test for Final NCPC Review	Test for Final NCPC Review	Strength established from Average of 5 samples. One Sample for NIST
	Torque Shear Strength	6	Test for Final NCPC Review	Test for Final NCPC Review	Test for Final NCPC Review	Strength established from Average of 5 samples. One Sample for NIST
316L ANNEALED ALLOY FOR INFORMATION AND REFERENCE ONLY	SAMPLES FOR MECHANICAL STRENGTH TESTING WITHOUT ENVIRONMENTAL CORROSION EXPOSURE					
	Shear Strength	6	6	6	6	Strength established from Average of 5 samples. One Sample for NIST
	Peel Strength	6	6	6	6	Strength established from Average of 5 samples. One Sample for NIST
	Torque Shear Strength	6	6	6	6	Strength established from Average of 5 samples. One Sample for NIST
	SAMPLES FOR MECHANICAL WELD STRENGTH WITH ENVIRONMENTAL CORROSION EXPOSURE					
	Shear Strength	6	6	6	6	Strength established from Average of 5 samples. One Sample for NIST
	Peel Strength	6	6	6	6	Strength established from Average of 5 samples. One Sample for NIST
	Torque Shear Strength	6	6	6	6	Strength established from Average of 5 samples. One Sample for NIST

Environmental Corrosion Testing Sample Matrix - Executive Summary

Alloy	Enironmental Corrosion Test Samples	Joint Type 1 # of samples 7X7 Twisted Wire to 7x7 Twisted Wire	Joint Type 2 # of samples 1-16 Braided Wire to 7x7 Twisted Wire	Joint Type 3 # of samples 1-16 Braided Wire to 1-24 Braided Wire	Joint Type 4 # of samples 1-24 Braided Wire to 2-24 Braided Wire	Notes
317L	Control	2	Test For Final NCPC Review	Test For Final NCPC Review	Test For Final NCPC Review	Sample does not go in Salt Fog chamber
	Environmental Salt Fog	3	Test For Final NCPC Review	Test For Final NCPC Review	Test For Final NCPC Review	
	Environmental Salt Fog / Descaled and Passivated	3	Test For Final NCPC Review	Test For Final NCPC Review	Test For Final NCPC Review	Samples to be descaled and passivated prior to salt fog test
316L	Control	2	2	2	2	Sample does not go in Salt Fog chamber
	Environmental Salt Fog	3	3	3	3	
	Environmental Salt Fog / Descaled and Passivated	3	3	3	3	Samples to be descaled and passivated prior to salt fog test

TEST SAMPLE TOTAL SUMMARY

Environmental Test & Mechanical Strength Test Samples	48	24	24	24	120
Mechanical Strength Test Samples (no evironmental exposure)	36	18	18	18	90
Control Samples	4	2	2	2	10
TOTALS	88	44	44	44	220

Color Key: Samples that are Environmentally Tested in Salt Fog Chamber

NCPC Preliminary Review

Weld Strength and Environmental Sample Matrix

Structural Twisted Wire and Art Braided Wire

Color Key: Samples that are Environmentally Tested in Salt Fog Chamber

317L ANNEALED ALLOY REPRESENTATIVE SAMPLES OF THE PROJECT 1B SET

Sample #	Sample Material	Salt Fog Test***	Descaled	Passivated	WELD SETTINGS Power - Voltage (w)	Pressure (lbs)	Up-Ramp	T - Hold Time (ms)	Step Weld Distance	Documentation Process
1B SET JOINT TYPE 1 - 317L Structural 7x7 Twisted Wire to 317L Structural 7x7 Twisted Wire										
WELD STRENGTH TESTS COMPLETED PRIOR ENVIRONMENTAL TESTING										
1	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 1 thru 5
2	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 1 thru 5
3	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 1 thru 5
4	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 1 thru 5
5	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 1 thru 5
6	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		W
7	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 7 thru 11
8	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 7 thru 11
9	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 7 thru 11
10	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 7 thru 11
11	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 7 thru 11
12	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Sample Provided to NIST
13	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 13 thru 17
14	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 13 thru 17
15	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 13 thru 17
16	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 13 thru 17
17	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 13 thru 17
18	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Sample Provided to NIST
WELD STRENGTH TESTS COMPLETED AFTER ENVIRONMENTAL TESTING										
19	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 19 thru 23
20	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 19 thru 23
21	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 19 thru 23
22	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 19 thru 23
23	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 19 thru 23
24	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2 Sample provided to NIST
25	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 25 thru 29
26	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 25 thru 29
27	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 25 thru 29
28	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 25 thru 29
29	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 25 thru 29
30	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
31	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 31 thru 35
32	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 31 thru 35
33	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 31 thru 35
34	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 31 thru 35
35	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 31 thru 35
36	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
ENVIRONMENTAL TESTING										
37	Environmental Sample	X			38%	10 lbs	1ms	1ms		1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
38	Environmental Sample	X			38%	10 lbs	1ms	1ms		1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
39	Environmental Sample	X			38%	10 lbs	1ms	1ms		1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
40	Environmental Sample	X	X	X	38%	10 lbs	1ms	1ms		1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
41	Environmental Sample	X	X	X	38%	10 lbs	1ms	1ms		1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
42	Environmental Sample	X	X	X	38%	10 lbs	1ms	1ms		1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
43	Control Sample				38%	10 lbs	1ms	1ms		Reference sample: 1) Photograph and document sample at weld interface and general wire condition away from weld.
44	Control Sample				38%	10 lbs	1ms	1ms		Reference sample: 1) Photograph and document sample at weld interface and general wire condition away from weld. Sample Provided to NIST

NCPC Preliminary Review

Weld Strength and Environmental Sample Matrix

Structural Twisted Wire and Art Braided Wire

Color Key: [ ] Samples that are Environmentally Tested in Salt Fog Chamber

316L ANNEALED ALLOY FOR REFERENCE ONLY 2B SET

					WELD SETTINGS					
Sample #	Sample Material	Salt Fog Test***	Descaled	Passivated	Power - Voltage (w)	Pressure (lbs)	Up-Ramp	T - Hold Time (ms)	Step Weld Distance	Documentation Process
2B SET JOINT TYPE 1 - 316L Structural 7x7 Twisted Wire to 316L Structural 7x7 Twisted Wire										
WELD STRENGTH TESTS COMPLETED PRIOR ENVIRONMENTAL TESTING										
51	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 51 thru 55
52	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 51 thru 55
53	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 51 thru 55
54	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 51 thru 55
55	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 51 thru 55
56	Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Sample provided to NIST
57	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 57 thru 61
58	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 57 thru 61
59	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 57 thru 61
60	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 57 thru 61
61	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 57 thru 61
62	Peel Weld Strength Sample				38%	10 lbs	1ms	1ms		Sample provided to NIST
63	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 63 thru 67
64	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 63 thru 67
65	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 63 thru 67
66	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 63 thru 67
67	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Pull Tension Test - average five samples - 63 thru 67
68	Torque Shear Weld Strength Sample				38%	10 lbs	1ms	1ms		Sample provided to NIST
WELD STRENGTH TESTS COMPLETED AFTER ENVIRONMENTAL TESTING										
69	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 69 thru 73
70	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 69 thru 73
71	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 69 thru 73
72	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 69 thru 73
73	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load -69 thru 73
74	Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
75	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 75 thru 79
76	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 75 thru 79
77	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 75 thru 79
78	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load -75 thru 79
79	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 75 thru 79
80	Peel Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
81	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 80 thru 84
82	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 80 thru 84
83	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 80 thru 84
84	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 80 thru 84
85	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 80 thru 84
86	Torque Shear Weld Strength Sample	X			38%	10 lbs	1ms	1ms		1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
ENVIRONMENTAL TESTING										
87	Environmental Sample	X			38%	10 lbs	1ms	1ms		1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
88	Environmental Sample	X			38%	10 lbs	1ms	1ms		1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
89	Environmental Sample	X			38%	10 lbs	1ms	1ms		1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
90	Environmental Sample	X	X	X	38%	10 lbs	1ms	1ms		1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
91	Environmental Sample	X	X	X	38%	10 lbs	1ms	1ms		1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
92	Environmental Sample	X	X	X	38%	10 lbs	1ms	1ms		1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
93	Control Sample				38%	10 lbs	1ms	1ms		Reference sample: 1) Photograph and document sample at weld interface and general wire condition away from weld.
94	Control Sample				38%	10 lbs	1ms	1ms		Reference sample: 1) Photograph and document sample at weld interface and general wire condition away from weld.

NCPC Preliminary Review

Weld Strength and Environmental Sample Matrix

Structural Twisted Wire and Art Braided Wire

Color Key: [shaded] Samples that are Environmentally Tested in Salt Fog Chamber

316L ANNEALED ALLOY FOR REFERENCE ONLY 3B SET

Sample #	Sample Material	Salt Fog Test***	Descaled	Passivated	WELD SETTINGS: Power - Voltage (w)	Pressure (lbs)	Up-Ramp	T - Hold Time (ms)	Step Weld Distance	Documentation Process
3B SET JOINT TYPE 2 - 316L Art 1-16 Braided Wire to 316L Structural 7x7 Twisted Wire										
WELD STRENGTH TESTS COMPLETED PRIOR ENVIRONMENTAL TESTING										
101	Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 101 thru 105
102	Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples -101 thru 105
103	Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 101 thru 105
104	Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 101 thru 105
105	Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 101 thru 105
106	Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Sample provided to NIST
107	Peel Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 107 thru 111
108	Peel Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 107 thru 111
109	Peel Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 107 thru 111
110	Peel Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 107 thru 111
111	Peel Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 107 thru 111
112	Peel Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Sample provided to NIST
113	Torque Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 113 thru 117
114	Torque Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 113 thru 117
115	Torque Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 113 thru 117
116	Torque Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 113 thru 117
117	Torque Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 113 thru 117
118	Torque Shear Weld Strength Sample				33%	10 lbs	1ms	1ms	5/8"	Sample provided to NIST
WELD STRENGTH TESTS COMPLETED AFTER ENVIRONMENTAL TESTING										
119	Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 119 thru 123
120	Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 119 thru 123
121	Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 119 thru 123
122	Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load -119 thru 123
123	Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 119 thru 123
124	Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
125	Peel Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 125 thru 129
126	Peel Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 125 thru 129
127	Peel Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 125 thru 129
128	Peel Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 125 thru 129
129	Peel Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 125 thru 129
130	Peel Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
131	Torque Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 131 thru 135
132	Torque Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 131 thru 135
133	Torque Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 131 thru 135
134	Torque Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 131 thru 135
135	Torque Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 131 thru 135
136	Torque Shear Weld Strength Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
ENVIRONMENTAL TESTING										
137	Environmental Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
138	Environmental Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
139	Environmental Sample	X			33%	10 lbs	1ms	1ms	5/8"	1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
140	Environmental Sample	X	X	X	33%	10 lbs	1ms	1ms	5/8"	1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
141	Environmental Sample	X	X	X	33%	10 lbs	1ms	1ms	5/8"	1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
142	Environmental Sample	X	X	X	33%	10 lbs	1ms	1ms	5/8"	1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
143	Control Sample				33%	10 lbs	1ms	1ms	5/8"	Reference sample: 1) Photograph and document sample at weld interface and general wire condition away from weld.
144	Control Sample				33%	10 lbs	1ms	1ms	5/8"	Reference sample: 1) Photograph and document sample at weld interface and general wire condition away from weld.

Eisenhower Memorial
Tapestry Engineering and Data Summary
February 5, 2014

NCPC Preliminary Review

Weld Strength and Environmental Sample Matrix

Structural Twisted Wire and Art Braided Wire

Color Key: [shaded] Samples that are Environmentally Tested in Salt Fog Chamber

316L ANNEALED ALLOY FOR REFERENCE ONLY 4B SET

Sample #	Sample Material	Salt Fog Test***	Descaled	Passivated	WELD SETTINGS Power - Voltage (w)	Pressure (lbs)	Up-Ramp	T - Hold Time (ms)	Step Weld Distance	Documentation Process
4B SET JOINT TYPE 3 - 316L Art 1-16 Braided Wire to 316L Art 1-24 Braided Wire										
WELD STRENGTH TESTS COMPLETED PRIOR ENVIRONMENTAL TESTING										
151	Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 151 thru 155
152	Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 151 thru 155
153	Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 151 thru 155
154	Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 151 thru 155
155	Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 151 thru 155
156	Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Sample provided to NIST
157	Peel Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 157 thru 161
158	Peel Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 157 thru 161
159	Peel Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples -157 thru 161
160	Peel Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 157 thru 161
161	Peel Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples -157 thru 161
162	Peel Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Sample provided to NIST
163	Torque Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 163 thru 167
164	Torque Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 163 thru 167
165	Torque Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 163 thru 167
166	Torque Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 163 thru 167
167	Torque Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Pull Tension Test - average five samples - 163 thru 167
168	Torque Shear Weld Strength Sample				50%	10 lbs	1ms	1ms	5/8"	Sample provided to NIST
WELD STRENGTH TESTS COMPLETED AFTER ENVIRONMENTAL TESTING										
169	Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 169 thru 173
170	Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 169 thru 173
171	Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 169 thru 173
172	Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 169 thru 173
173	Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 169 thru 173
174	Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
175	Peel Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 175 thru 179
176	Peel Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 175 thru 179
177	Peel Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 175 thru 179
178	Peel Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 175 thru 179
179	Peel Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 175 thru 179
180	Peel Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
181	Torque Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 181 thru 185
182	Torque Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 181 thru 185
183	Torque Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 181 thru 185
184	Torque Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 181 thru 185
185	Torque Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load -181 thru 185
186	Torque Shear Weld Strength Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
ENVIRONMENTAL TESTING										
187	Environmental Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
188	Environmental Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
189	Environmental Sample	X			50%	10 lbs	1ms	1ms	5/8"	1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
190	Environmental Sample	X	X	X	50%	10 lbs	1ms	1ms	5/8"	1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
191	Environmental Sample	X	X	X	50%	10 lbs	1ms	1ms	5/8"	1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
192	Environmental Sample	X	X	X	50%	10 lbs	1ms	1ms	5/8"	1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
193	Control Sample				50%	10 lbs	1ms	1ms	5/8"	Reference sample: 1) Photograph and document sample at weld interface and general wire condition away from weld.
194	Control Sample				50%	10 lbs	1ms	1ms	5/8"	Reference sample: 1) Photograph and document sample at weld interface and general wire condition away from weld.

NCPC Preliminary Review

Weld Strength and Environmental Sample Matrix

Structural Twisted Wire and Art Braided Wire

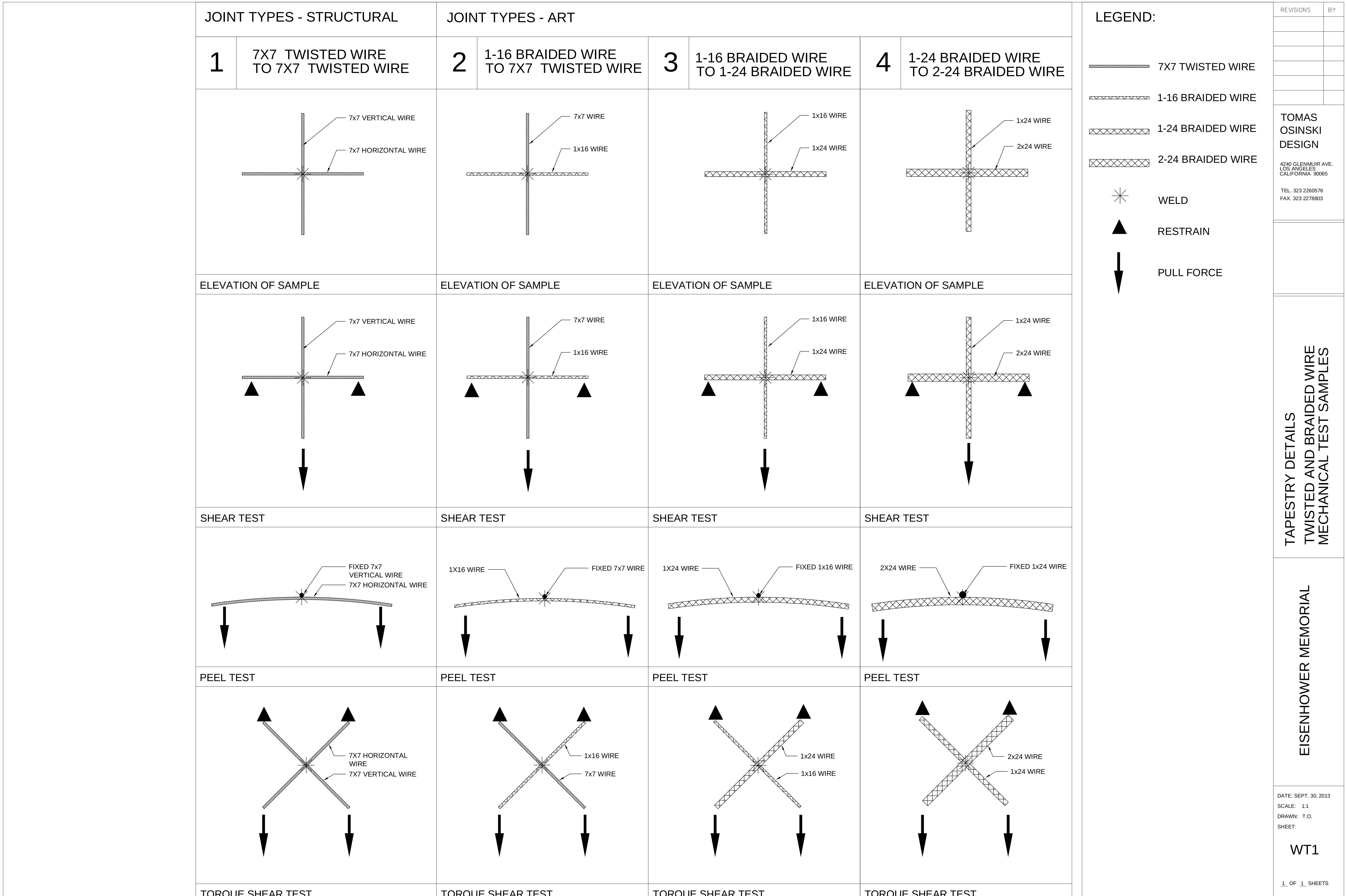
Color Key: [shaded] Samples that are Environmentally Tested in Salt Fog Chamber

316L ANNEALED ALLOY FOR REFERENCE ONLY 5B SET

Sample #	Sample Material	Salt Fog Test***	Descaled	Passivated	WELD SETTINGS Power - Voltage (w)	Pressure (lbs)	Up-Ramp	T - Hold Time (ms)	Step Weld Distance	Documentation Process
5B SET JOINT TYPE 4 - 316L Art 1-24 Braided Wire to 316L Art 2-24 Braided Wire										
WELD STRENGTH TESTS COMPLETED PRIOR ENVIRONMENTAL TESTING										
201	Shear Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 201 thru 205
202	Shear Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 201 thru 205
203	Shear Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 201 thru 205
204	Shear Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 201 thru 205
205	Shear Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 201 thru 205
206	Shear Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Sample provided to NIST
207	Peel Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 207 thru 211
208	Peel Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 207 thru 211
209	Peel Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 207 thru 211
210	Peel Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 207 thru 211
211	Peel Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 207 thru 211
212	Peel Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Sample provided to NIST
213	Torque Shear Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 213 thru 216
214	Torque Shear Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 213 thru 216
215	Torque Shear Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 213 thru 216
216	Torque Shear Weld Strength Sample				70%	10 lbs	2 ms	1ms	5/8"	Pull Tension Test - average five samples - 213 thru 216
217	Torque Shear Weld Strength Sample				70%	10 lbs	2 ms	1 ms	5/8"	Pull Tension Test - average five samples - 213 thru 216
218	Torque Shear Weld Strength Sample				70%	10 lbs	2 ms	1 ms	5/8"	Sample provided to NIST
WELD STRENGTH TESTS COMPLETED AFTER ENVIRONMENTAL TESTING										
219	Shear Weld Strength Sample	X			70%	10 lbs	2 ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 219 thru 223
220	Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 219 thru 223
221	Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 219 thru 223
222	Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 219 thru 223
223	Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 219 thru 223
224	Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
225	Peel Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 225 thru 229
226	Peel Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 225 thru 229
227	Peel Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 225 thru 229
228	Peel Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 225 thru 229
229	Peel Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 225 thru 229
230	Peel Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
231	Torque Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 231 thru 235
232	Torque Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 231 thru 235
233	Torque Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 231 thru 235
234	Torque Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 231 thru 235
235	Torque Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Pull Tension Test after 1000 hours - average five samples for load - 231 thru 235
236	Torque Shear Weld Strength Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) 1000 Hour Salt Fog Test 2) Sample provided to NIST
ENVIRONMENTAL TESTING										
237	Environmental Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
238	Environmental Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
239	Environmental Sample	X			70%	10 lbs	2ms	1 ms	5/8"	1) Photograph and document sample at weld interface and general wire condition away from weld. 2) 1000 Hour Salt Fog Test. 3) Photograph and document sample at weld interface and general wire condition away from weld.
240	Environmental Sample	X	X	X	70%	10 lbs	2ms	1 ms	5/8"	1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
241	Environmental Sample	X	X	X	70%	10 lbs	2ms	1 ms	5/8"	1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
242	Environmental Sample	X	X	X	70%	10 lbs	2ms	1 ms	5/8"	1) Descale and passivate the sample 2) Photograph and document sample at weld interface and general wire condition away from weld. 3) 1000 Hour Salt Fog Test. 4) Photograph and document sample at weld interface and general wire condition away from weld.
243	Control Sample				70%	10 lbs	2ms	1 ms	5/8"	Reference sample: 1) Photograph and document sample at weld interface and general wire condition away from weld.
244	Control Sample				70%	10 lbs	2ms	1 ms	5/8"	Reference sample: 1) Photograph and document sample at weld interface and general wire condition away from weld.

Notes	
Salt Fog Test***	Performed per ASTM G85-09 Annex A4, Cycle A4.4.4.1. 1000 hours A 95+- 3 degrees, with constant spray of 5% +- 1 % wt NaCl, with in injection of SO2 gas every five hours to maintain pH of 2.5-3.2 environmental testing.
	All samples to be weighted with 2lbs during environmental testing. Carbon Black applied to all samples prior to environmental test.

EXHIBIT 3


JOINT TYPES - STRUCTURAL
JOINT TYPES - ART
1 7X7 TWISTED WIRE TO 7X7 TWISTED WIRE
2 1-16 BRAIDED WIRE TO 7X7 TWISTED WIRE
3 1-16 BRAIDED WIRE TO 1-24 BRAIDED WIRE
4 1-24 BRAIDED WIRE TO 2-24 BRAIDED WIRE
7x7 VERTICAL WIRE
7x7 HORIZONTAL WIRE
7x7 WIRE
1x16 WIRE
1x24 WIRE
2x24 WIRE
ELEVATION OF SAMPLE
SHEAR TEST
FIXED 7x7 VERTICAL WIRE
7X7 HORIZONTAL WIRE
1X16 WIRE
FIXED 7x7 WIRE
1X24 WIRE
FIXED 1x16 WIRE
2X24 WIRE
FIXED 1x24 WIRE
PEEL TEST
7X7 HORIZONTAL WIRE
7X7 VERTICAL WIRE
7x7 WIRE
TORQUE SHEAR TEST
LEGEND:
7X7 TWISTED WIRE
1-16 BRAIDED WIRE
1-24 BRAIDED WIRE
2-24 BRAIDED WIRE
WELD
RESTRAIN
PULL FORCE
REVISIONS
BY
TOMAS OSINSKI DESIGN
4240 GLENMUIR AVE.
LOS ANGELES
CALIFORNIA 90065
TEL. 323 2260576
FAX. 323 2278803
TAPESTRY DETAILS
TWISTED AND BRAIDED WIRE
MECHANICAL TEST SAMPLES
EISENHOWER MEMORIAL
DATE: SEPT. 30, 2013
SCALE: 1:1
DRAWN: T.O.
SHEET:
WT1
1 OF 1 SHEETS

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4.3 ENVIRONMENTAL CORROSION TEST - TWISTED AND BRAIDED WIRE

Included in this section:

- Element Materials Technology Report # TOM002-21955 Corrosion Titled *Corrosion Analysis of Welded Samples*
- Anachem Laboratories Test Report dated December 3, 2013

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Element Report #: TOM002-21955C

Corrosion Analysis of Welded Samples

Prepared by:

Hugo A. Menendez, MS, P.E.
Department Manager, Failure Analysis, Metallurgist
Element Materials Technology – Huntington Beach

INTRODUCTION

Element personnel were asked to provide mechanical and metallurgical testing services to Tomas Osinski Design in support of the Eisenhower Memorial Tapestry Project.

It should be noted that alloy 317L stainless steel which was selected by the design team as the optimum material for the tapestry was only available in the structural wire form at the time of testing. None of the art braided wire was available in alloy 317L at the time of testing. Alloy 316L stainless steel which had previously been a candidate alloy was available in all forms and was included in the study for comparison purposes but is not being considered as the preferred alloy for construction of the tapestries. Corrosion tests of braided art wires made from alloy 317L are planned and will be forthcoming once the material is available.

OBJECTIVE

The objective of this study was to examine and characterize the condition of various salt spray tested (ASTM G85 – 11 Annex A4, Cycle A4.4.1) stainless steel braided and twisted wire weld joints which will be used to construct the Eisenhower Memorial Tapestries.

OVERVIEW OF TEST SAMPLES

The tapestries will be constructed from four wire types and one alloy type, 317L – one structural twisted wire and three nonstructural “art” braided wires. The schematic on the following page shows the four wire combination and weld joint types which will be used to construct the tapestries. The schematic also shows diagrams representing the mechanical strength tests which were performed on as-welded samples along with duplicate samples which had been corrosion tested. The focus of this report is the corrosion testing performed however some discussion regarding the strength testing performed is necessary in order to provide some perspective on the observations presented.

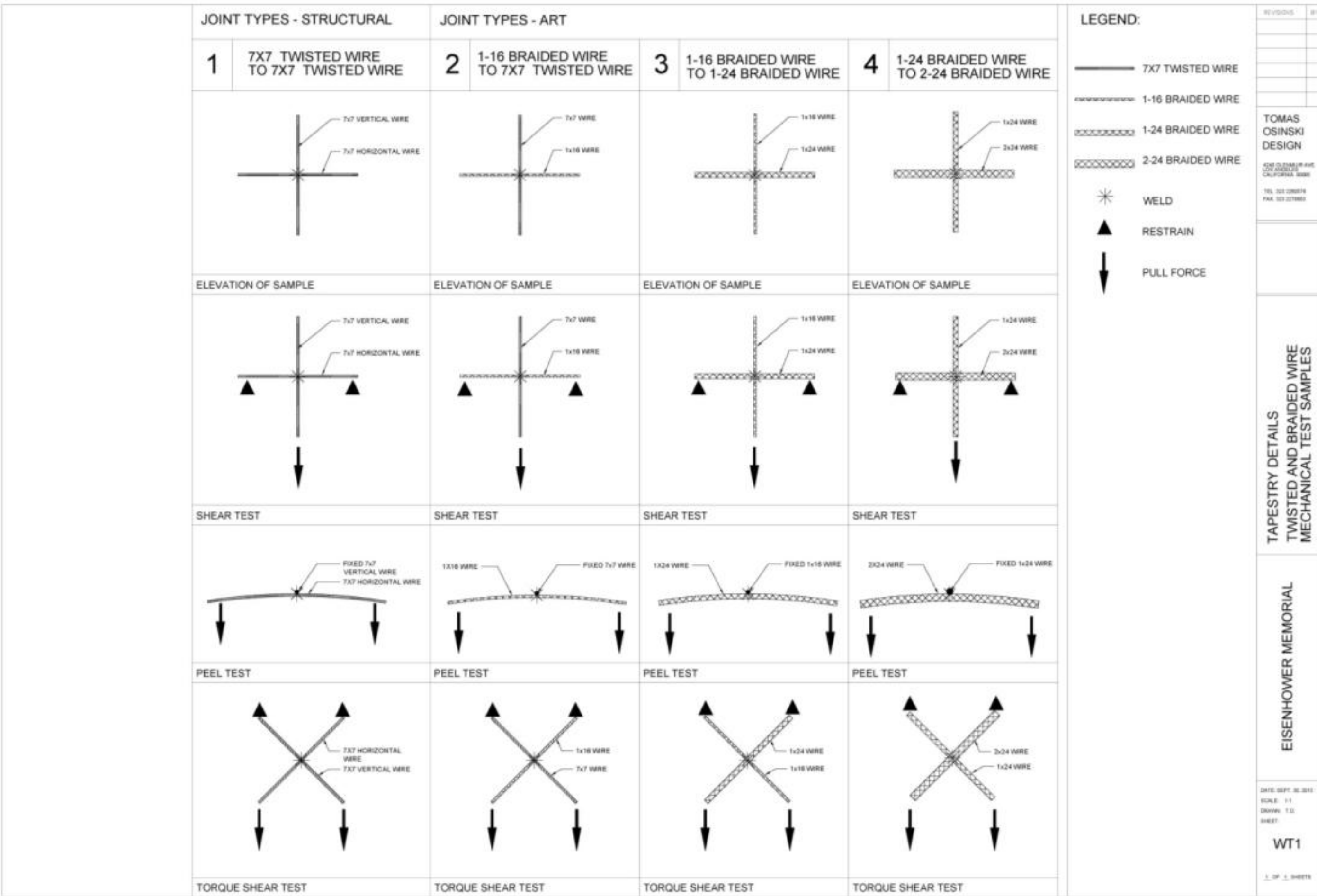
Different weld settings were used for each of the weld joint types. The structural wire welds for the alloy 316L samples and the alloy 317L samples were made using the same weld settings. Mechanical strength tests were performed on as-welded samples to establish base line properties. The same mechanical strength tests were performed on duplicate samples after exposing them to a 1000 hour SO_2 salt spray (fog) test.

One of the testing objectives was to look at whether descaling and passivation would have an effect on the corrosion resistance of the various weld joint types. A total of 15 samples were descaled, passivated and corrosion tested and examined for the presence of corrosion following the 1000 hour SO_2 salt spray (fog) test.

The test samples included alloy 317L and alloy 316L alloys for the structural wires. Due to availability, only alloy 316L was provided for the art braided weld joint Type 2, Type 3 and Type 4.

DIAGRAM ILLUSTRATING THE VARIOUS WELD JOINT ALLOYS AND MECHANICAL STRENGTH TESTS PERFORMED

EXHIBIT 3



The torque shear test diagram is not reflective of how the actual test was performed in that the actual joints were gripped from one side in order to create an unbalanced or non-symmetrical loading condition. Photographs of representative test samples are presented in Element Report # TOM002-04-04-21955M.

SUMMARY and CONCLUSIONS:

A total of 120 stainless steel braided and twisted wire weld joint test samples were salt fog tested for 1000 hours per ASTM Specification G85 Annex A4, Cycle A4.4.1 at Anachem Laboratories in El Segundo, California.

It should be noted that the sulfur dioxide salt spray test performed as per ASTM G85 Annex A4 is much more aggressive than the standard salt spray test detailed in ASTM B117 due to the periodic introduction of $S0_2$ which results in a highly acidified salt fog environment (pH 2.5 and 3.2). In addition, the test procedure included coating all of the samples with lamp black to simulate atmospheric contamination / soot, as well as applying a tensile stress in the form of a 2 lb weight to all samples.

Visual examinations were performed on all 30 of the mechanical strength tested structural weld joints (Type 1 joints, 15 alloy 316L samples and 15 alloy 317L samples). Visual examinations were also performed on the 25 corrosion tested samples specified in the Weld Strength and Environmental Sample Matrix. The visual examinations were performed using an optical stereo microscope at magnifications ranging from 7.5X to 75X. Digital stereo microscope images were taken using a Keyence VHX-2000. Select samples were further examined using a Scanning Electron Microscope.

The results of all the corrosion testing performed can be summarized by the key points presented below.

1) No obvious optical or SEM evidence of pitting attack was observed on the wires from the structural alloy 317L weld joints examined.

2) Pitting attack was observed on several of the welded wire samples from the structural alloy 316L samples examined.

3) Pitting attack on the structural alloy 316L wires, when present, was generally within 3 mm to 8 mm of the weld joint. No significant pitting was observed away from the welds. Pitting attack was not necessarily present on every sample examined.

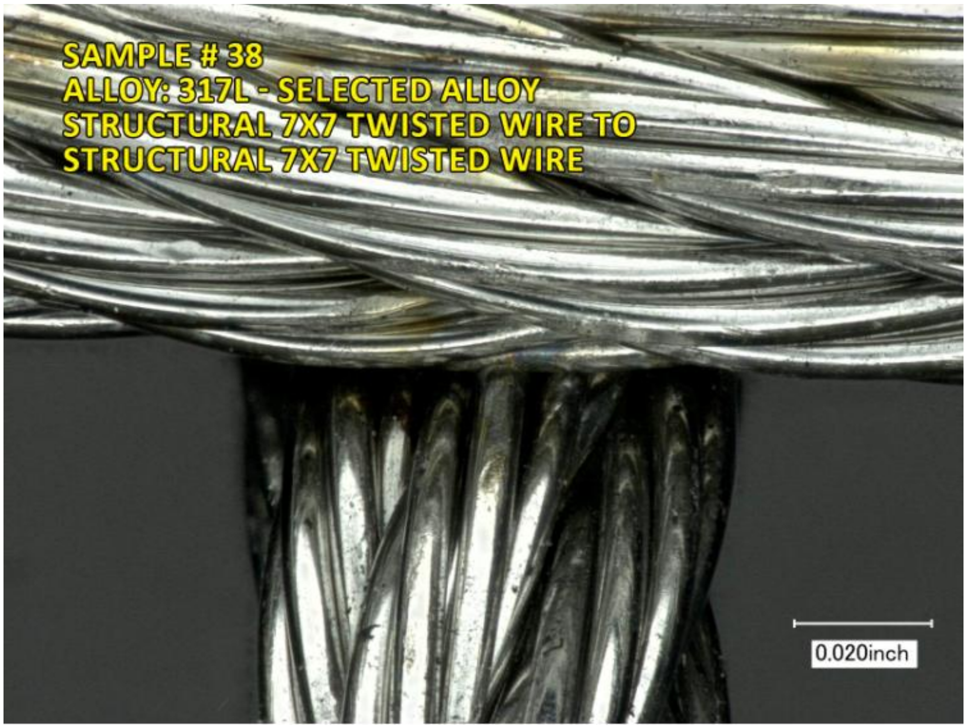
4) Pitting attack of alloy 316L welded art wires was present on numerous samples. Pitting attack was not necessarily present on every sample examined.

5) Descaling and passivation of the alloy 317L structural wires to remove heat tints did not result in a marked improvement in corrosion resistance given that the as-welded alloy 317L material showed no pitting attack to start with.

6) Descaling and passivation of the alloy 316L structural wire and art wire weld samples did not result in an obvious notable increase in pitting corrosion resistance compared to the samples which were not descaled.

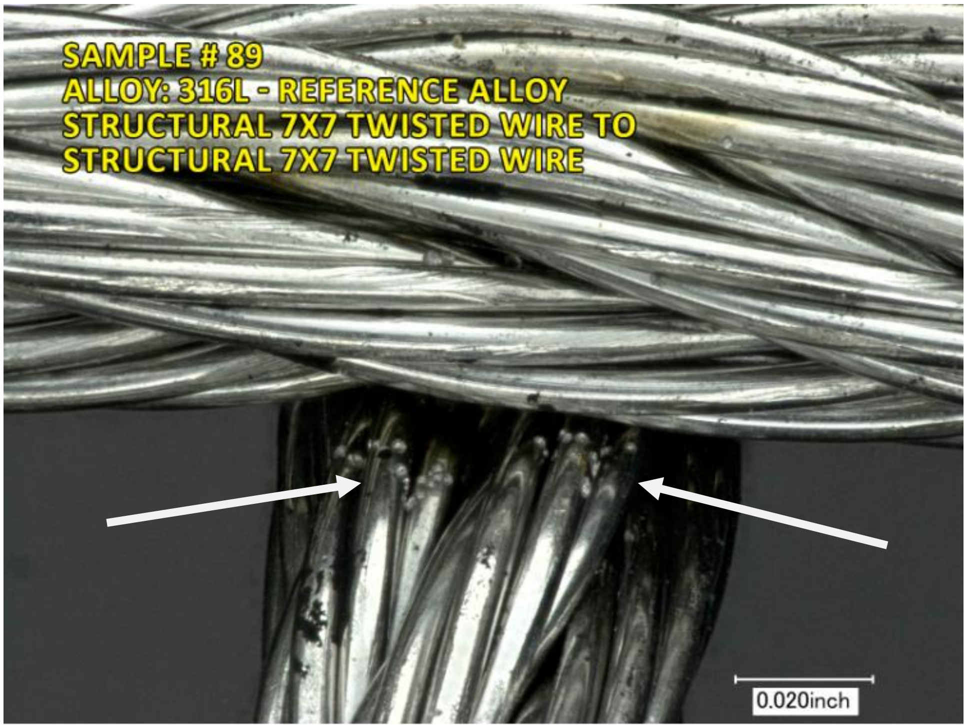
7) The current corrosion test results support the welded solid wire conclusions that welded Alloy 317L material possesses greater corrosion resistance than welded alloy 316L. This is especially evident given that the 1B and 2B samples were welded using the same parameters.

The variation in corrosion resistance between the two alloys tested is best illustrated by the high resolution digital stereomicroscope images presented on the following pages.

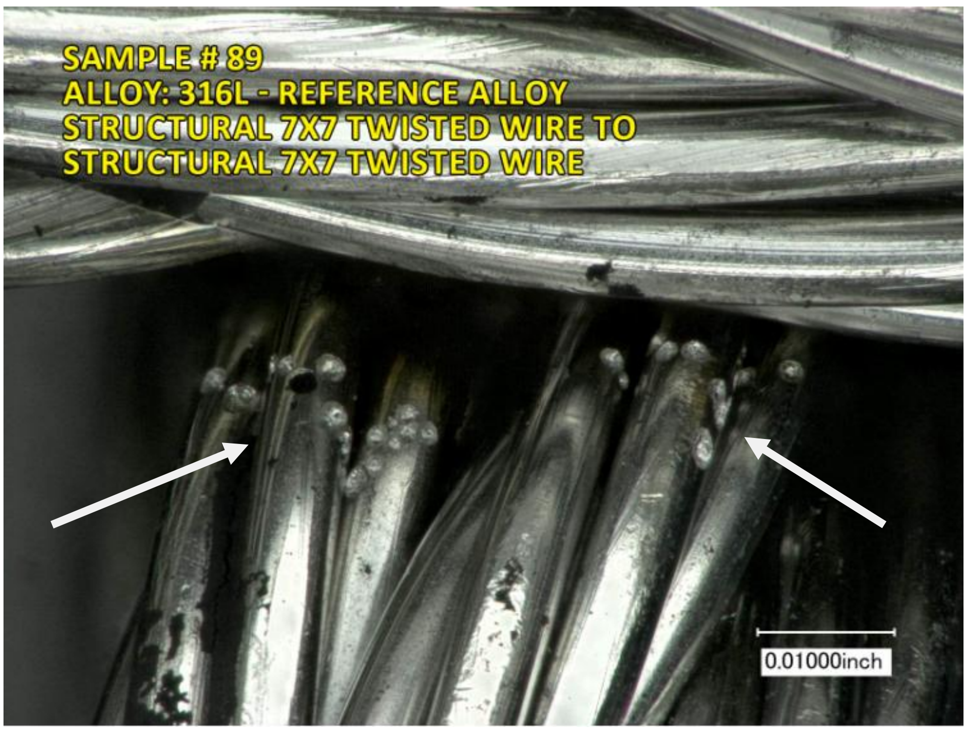


Alloy 317L structural wire weld joint showing no evidence of pitting (~35X magnification).

Alloy 317L structural wire weld joint showing no evidence of pitting (~70X magnification).



Alloy 316L structural wire weld joint (Sample #89) showing pitting marked with arrows (~35X magnification).



Alloy 316L structural wire weld joint showing a higher magnification view (~70X magnification) of the pitting attack from the previous page.

SUMMARY and CONCLUSIONS Continued:

The test results obtained from the current investigation support the conclusions obtained from the prior welded solid wire corrosion study; specifically that resistance welded alloy 317L material exhibits better corrosion resistance than resistance welded alloy 316L material in the sulfur dioxide salt spray test.

Alloy 317 stainless steel was specifically formulated to provide improved corrosion resistance over alloy 304 and alloy 316 stainless steel in highly corrosive process environments particularly in the presence of chlorides and other halides. The “L” designation refers to “low carbon” version of the same alloy which permits the material to be welded without concerns regarding sensitization.

The results of the corrosion tests performed to date directly reflect the durable nature of alloy 317L stainless steel relative to atmospheric corrosion and provide a firm basis for the decision to specify alloy 317L for construction of the tapestries.

It is worthwhile to note that none of the salt spray tested samples showed evidence of staining or rusting after the 1000 hour SO_2 salt spray exposure. Additionally, the mechanical strength samples showed no evidence to suggest corrosion had degraded the weld strength even after the 1000 hour SO_2 salt spray testing performed. The details of the mechanical strength testing performed on welded samples are presented in Element Report TOM002-04-04-21955M.

Stereo and SEM micrographs detailing the laboratory observations are presented for review.

CORROSION DISCUSSION:

Stainless steels are iron based alloys which in general have been alloyed with chromium and nickel and depending upon the specific alloy can contain varying amounts of molybdenum and or other corrosion resistance enhancing elements. Stainless steels derive their superior corrosion resistance from a thin surface film which is generally described as an oxide layer (≤ tens of angstroms). Stainless steels with greater than approximately 13 % chromium spontaneously passivate or more simply put become corrosion resistant in air saturated solutions, even in the presence of chloride ions.

The design team previously selected alloy 317L stainless steel as the optimum material for constructing the tapestries. Alloy 317L was selected based on earlier corrosion studies performed on solid wire samples made from several candidate alloys. Alloy 317L stainless steel is formulated with higher concentrations of chromium and molybdenum than alloy 316L stainless steel as shown in the table below (Chemical composition ranges taken from ASTM A240). The minimum nickel content of alloy 317L is also higher than the minimum nickel content of alloy 316L.

Alloy 317 stainless steel was formulated to provide improved corrosion resistance over alloy 304 and alloy 316 stainless steel in highly corrosive process environments particularly in the presence of chlorides and other halides. The "L" designation refers to "low carbon" which permits the material to be welded without concerns regarding sensitization.

Element	Percentage by weight (Maximum unless range is specified)	
	Alloy 316L	Alloy 317L
Carbon	0.03	0.03
Manganese	2.00	2.00
Silicon	0.75	0.75
Chromium	16.00 – 18.00	18.00 – 20.00
Nickel	10.00 – 14.00	11.00 – 15.00
Molybdenum	2.00 – 3.00	3.00 – 4.00
Phosphorous	0.045	0.045
Sulfur	0.03	0.03
Nitrogen	0.10	0.10
Iron	Balance	Balance

The values presented were obtained from ASTM A240.

The previous 1000 hour SO_2 salt spray corrosion studies performed on welded solid wire samples showed that pitting of the wires occurred in the immediate vicinity of the welds with the alloy 316L samples showing more evidence of pitting than the alloy 317L solid wire samples.

In the current investigation pitting attack was observed on welded joints made from the alloy 316L wires (both structural and art) however no evidence of pitting attack was observed in the alloy 317L welded samples.

CORROSION DISCUSSION CONTINUED:

The presence of heat tint oxides is believed to be the specific reason for the pitting attack observed in the welded solid wire samples previously tested. Oxidation of the welded sample surface(s) occurs as a result of oxygen in the air or in the purging gas in combination with the heat from welding. The thicker the oxide layer the darker the tint / discoloration.

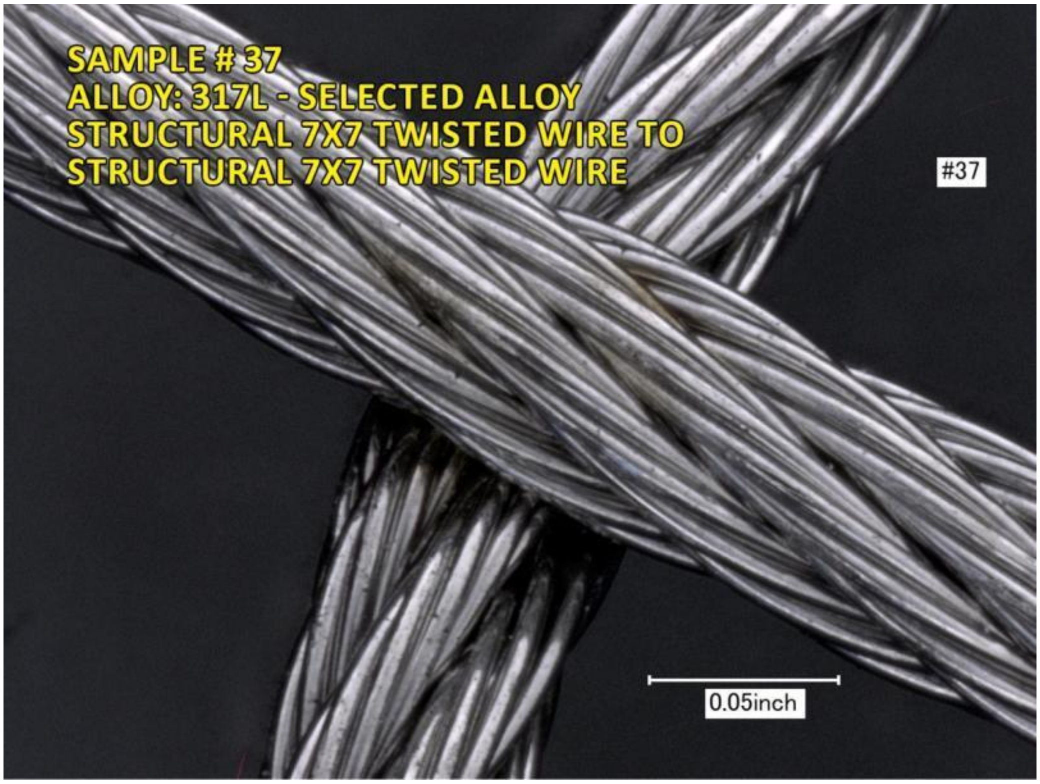
The chromium rich oxide can lower corrosion resistance in several ways. At welding temperatures between 300 C and 700 C a chromium depleted layer measuring approximately less than 1 – 2 microns thick is formed beneath the oxide scale. At high temperatures and or high oxygen levels, chromium can burn from the surface of the oxide leaving a corrosion sensitive iron oxide.

The extent to which heat tint can compromise corrosion resistance depends upon the inherent corrosion resistance of the material itself and the service environment. In the current round of salt spray tests there does not appear to be a notable difference in corrosion resistance between the alloy 317L samples which were descaled and passivated and exposed to salt fog compared to the as-welded alloy 317L samples which were salt fog tested. In general maximum corrosion resistance is obtained from samples which have been descaled (pickled) and passivated. The Nickel Development Institute Publication titled “Guidelines for the welded fabrication of nickel-containing stainless steels for corrosion resistant services No 11 007” states that heat tint seldom leads to corrosion in atmospheric or other mild environments but is frequently removed for cosmetic purposes

ASTM Specification A 380 – 06 titled “Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems” covers recommendations and precautions for the various processes available to remove heat tints and ensure maximum cleanliness of fabricated stainless steel items.

ASTM Specification A967 – 05 titled Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts” covers several different alloys of chemical passivation treatments for stainless steel parts along with recommendation and precautions.

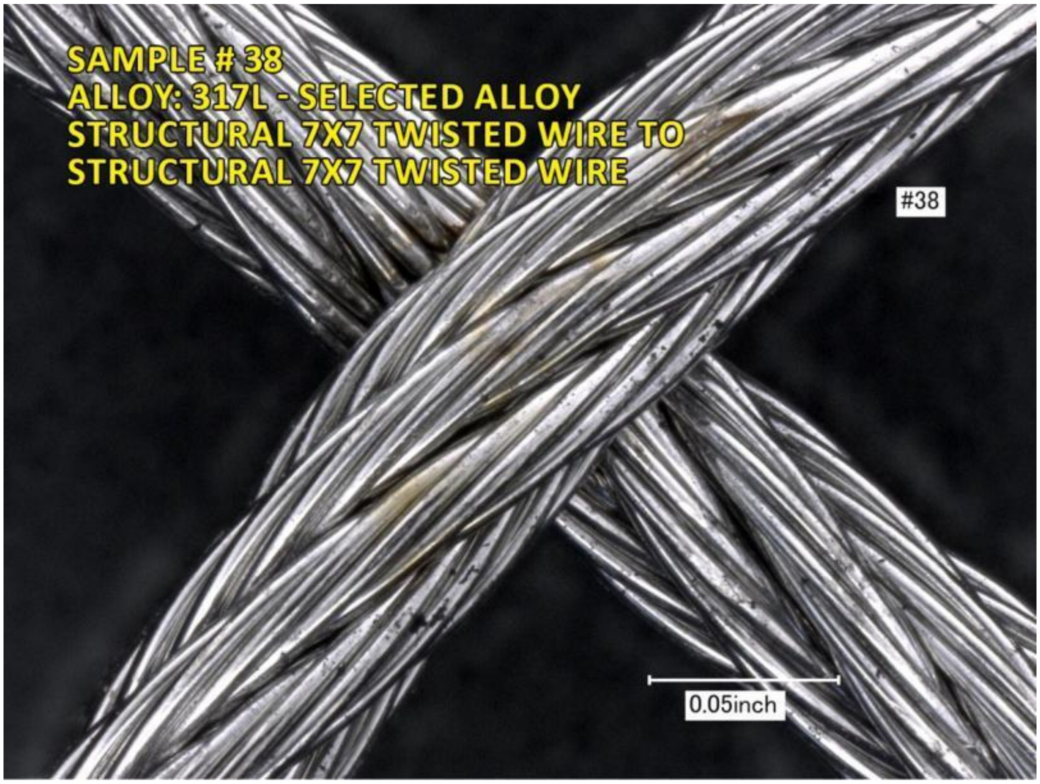
Digital stereo photographs showing comparison images between the alloy 317L and alloy 316L welded structural wire samples are presented for review on the following pages. To the unaided eye and even at low magnifications (20X – 40X) the variation in corrosion resistance between the two materials is almost imperceptible. Examination of the samples using higher magnifications was required in order to detect and document the results presented in this report.


SAMPLE # 37
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#37
0.05inch

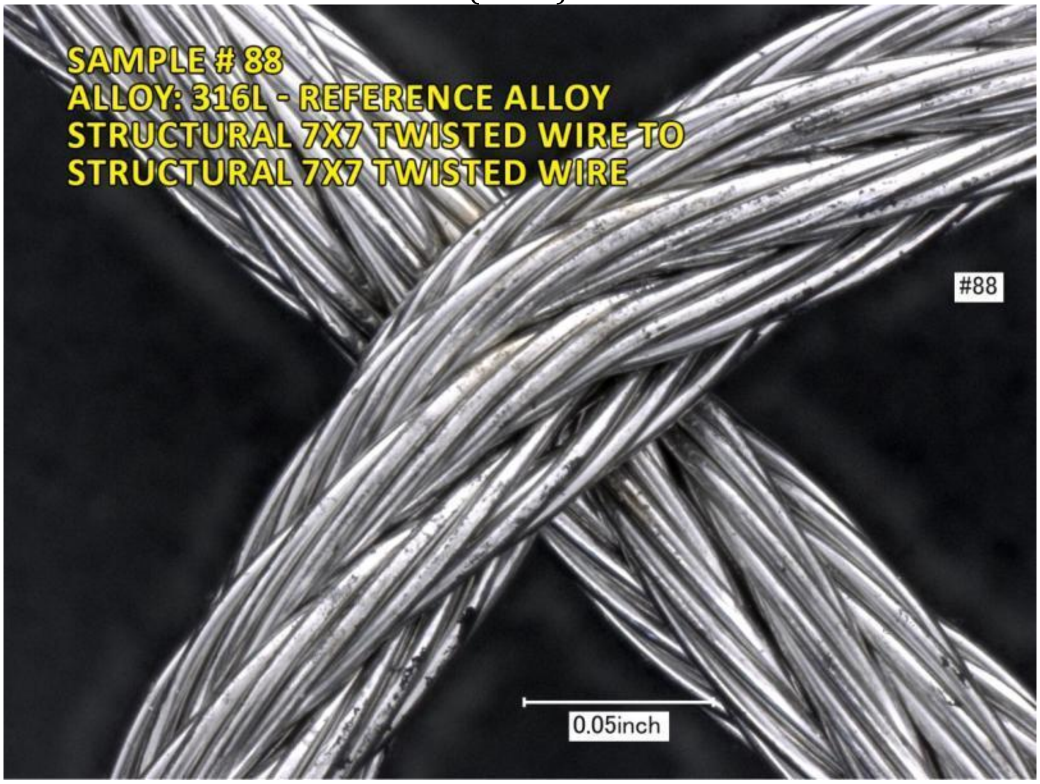
(~20X)


SAMPLE # 87
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#87
0.05inch

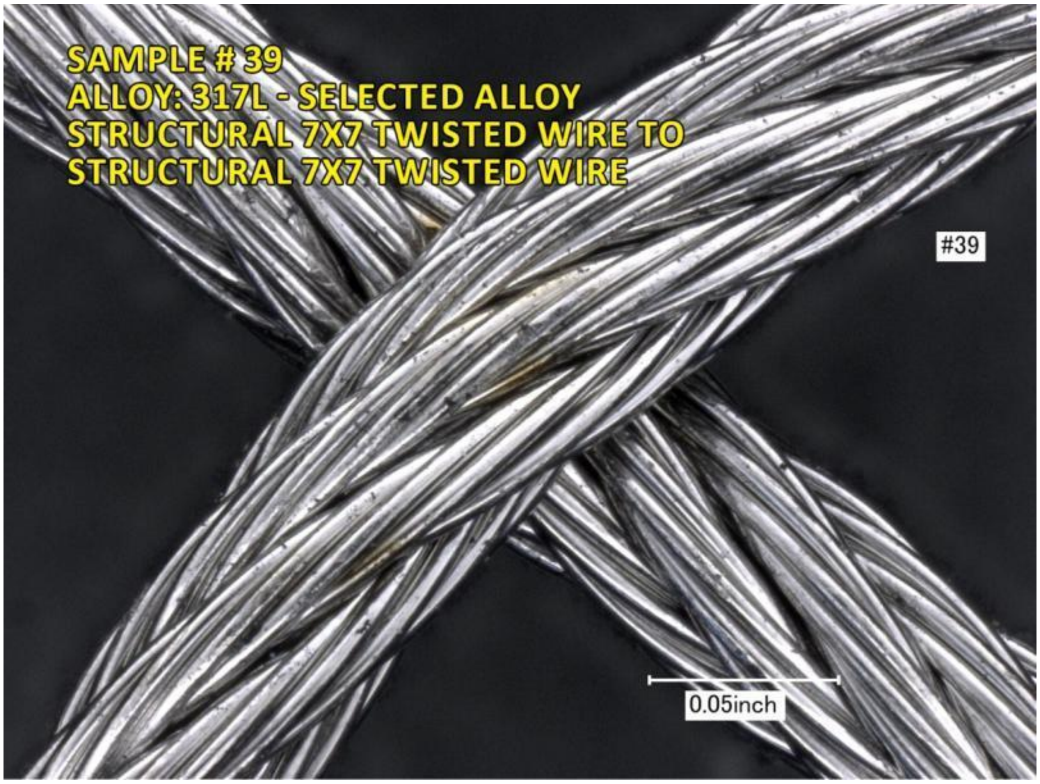
(~20X)


SAMPLE # 38
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#38
0.05inch

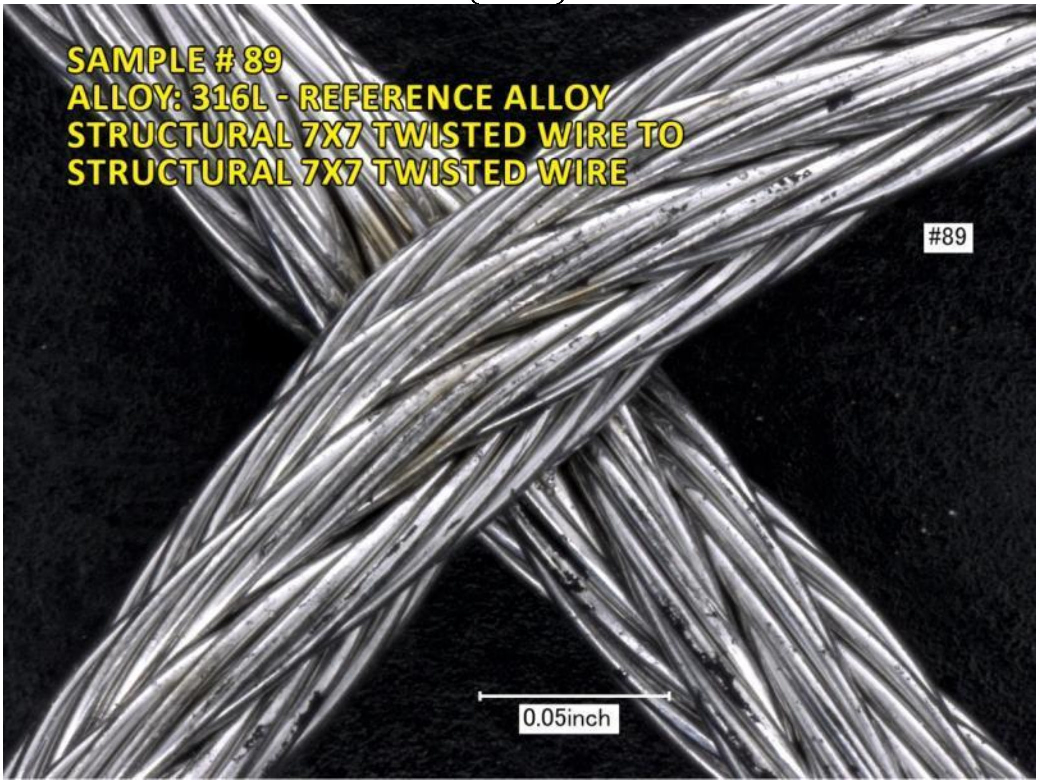
(~20X)


SAMPLE # 88
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#88
0.05inch

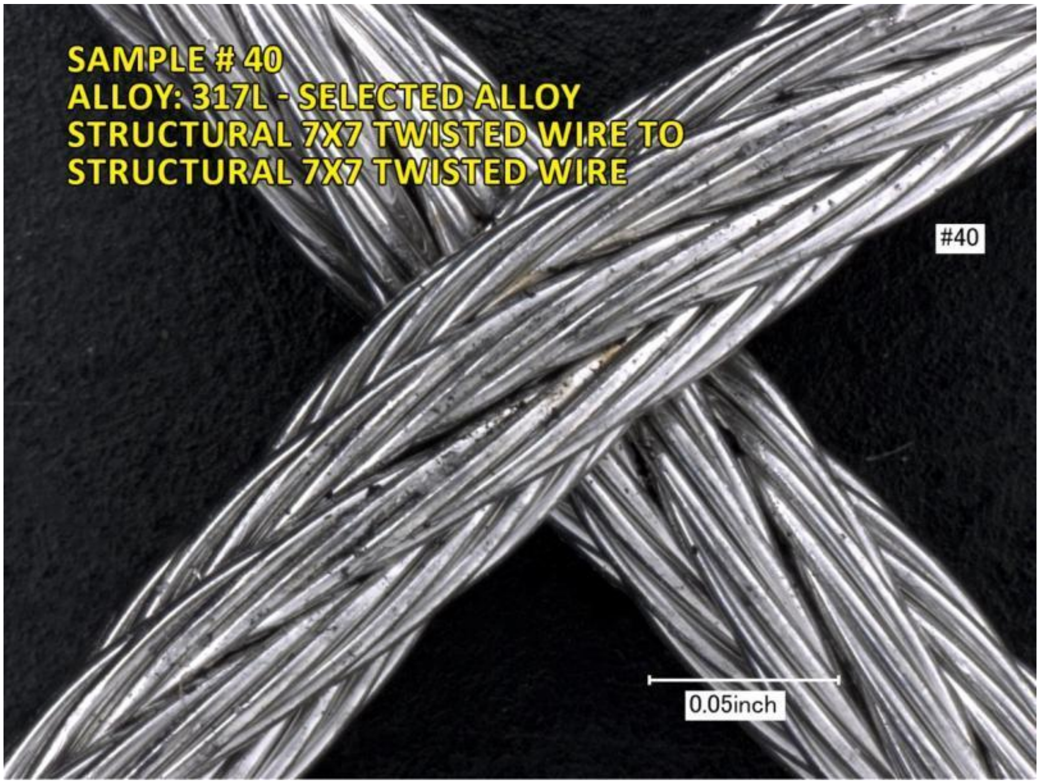
(~20X)


SAMPLE # 39
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#39
0.05inch

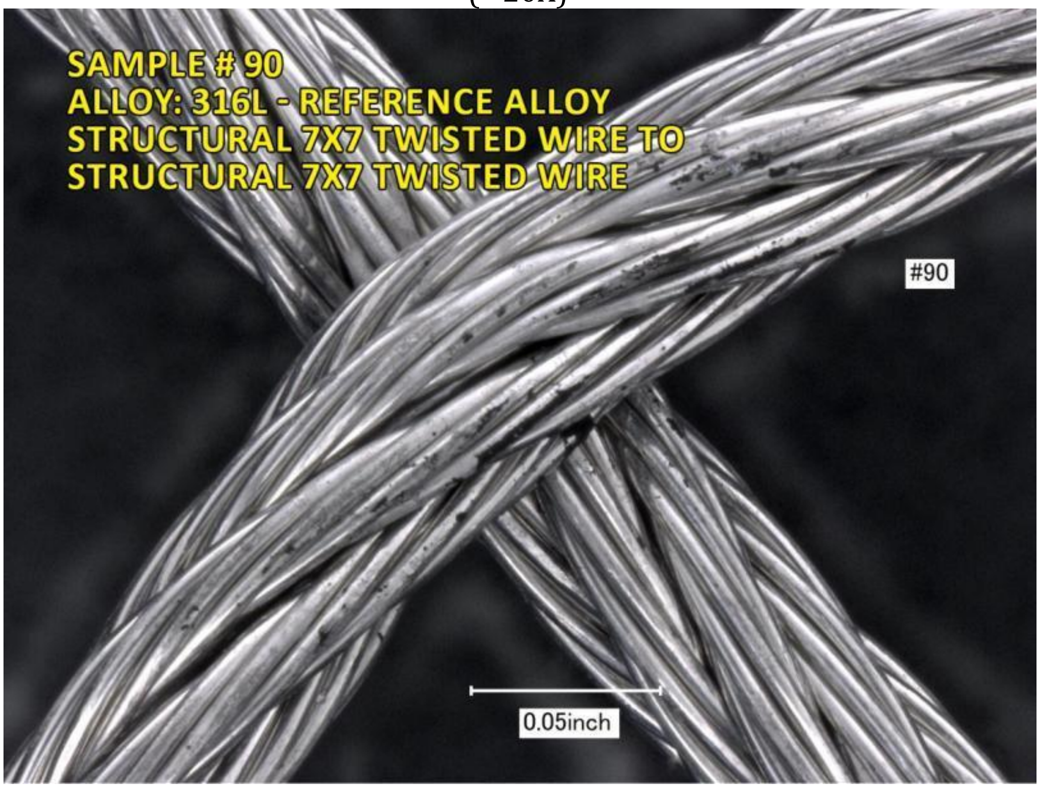
(~20X)


SAMPLE # 89
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#89
0.05inch

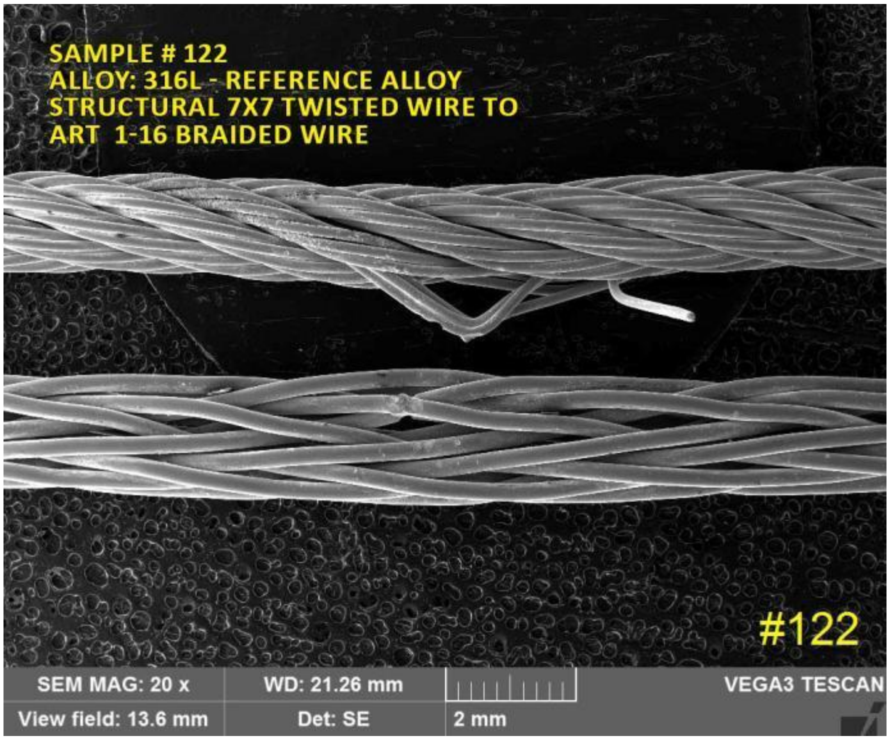
(~20X)

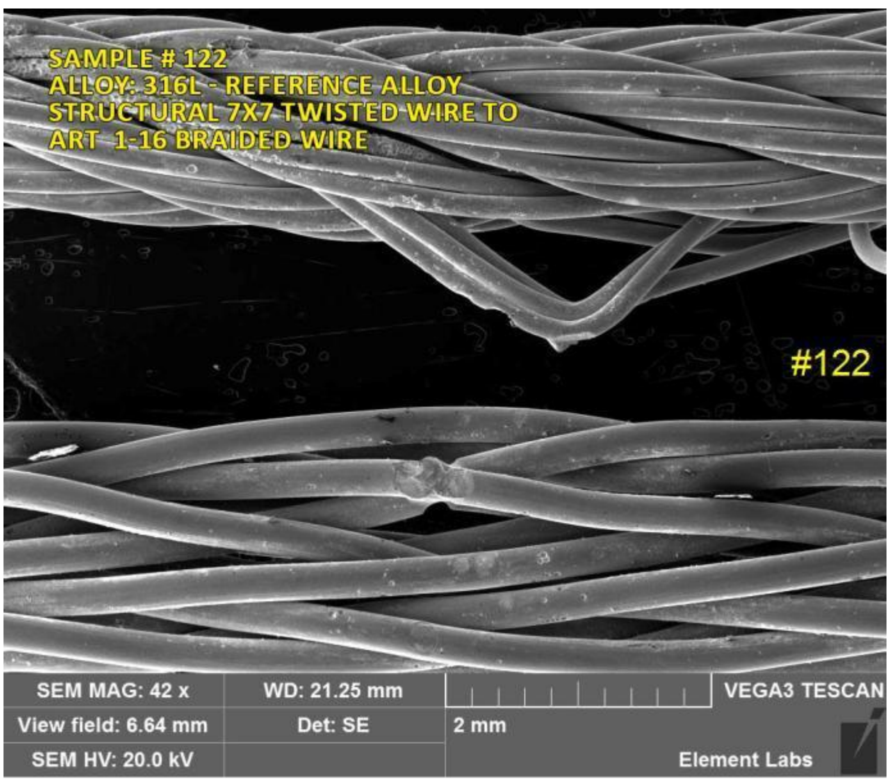

SAMPLE # 40
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#40
0.05inch

(~20X)

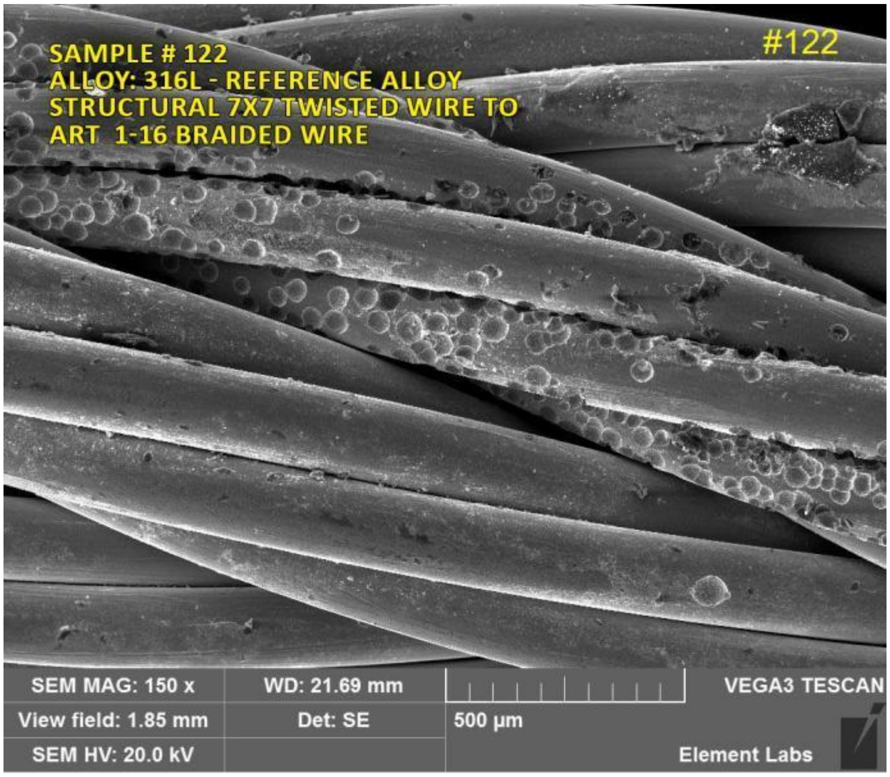

SAMPLE # 90
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#90
0.05inch

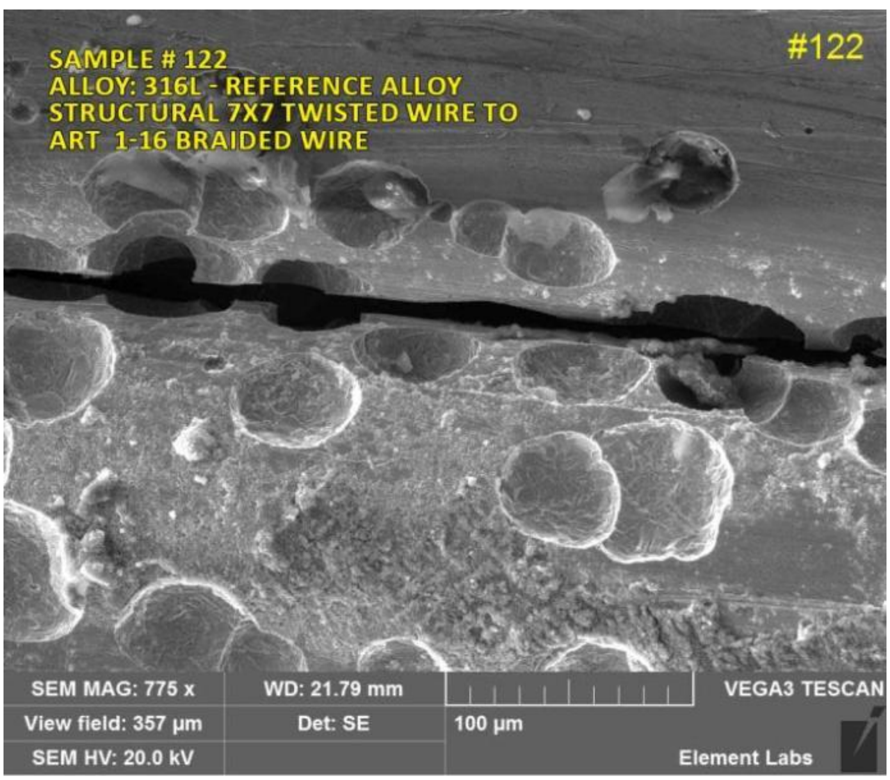
(~20X)



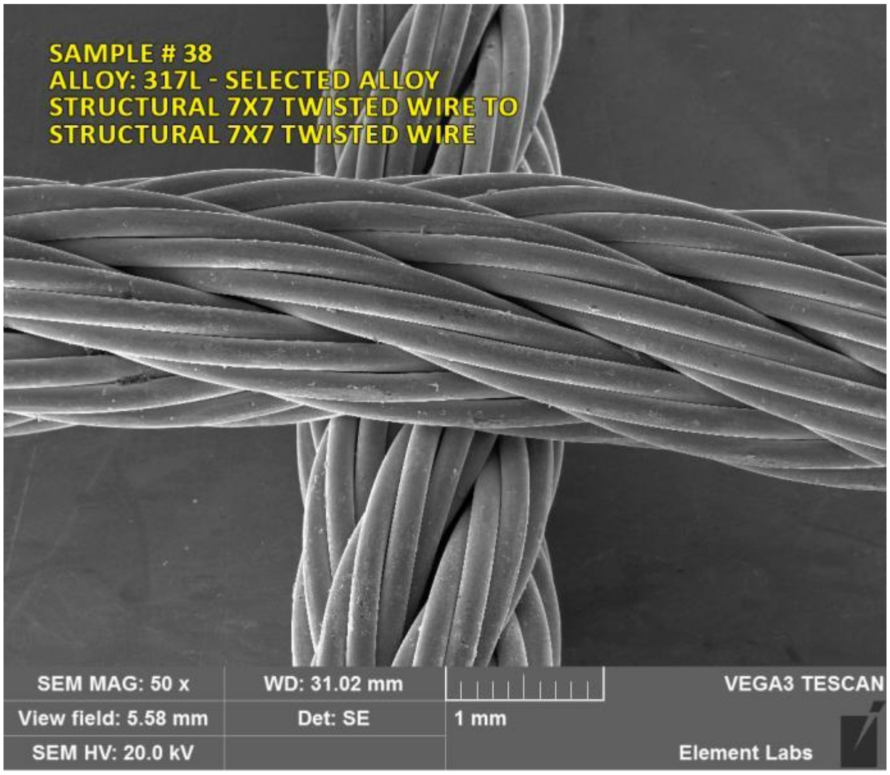


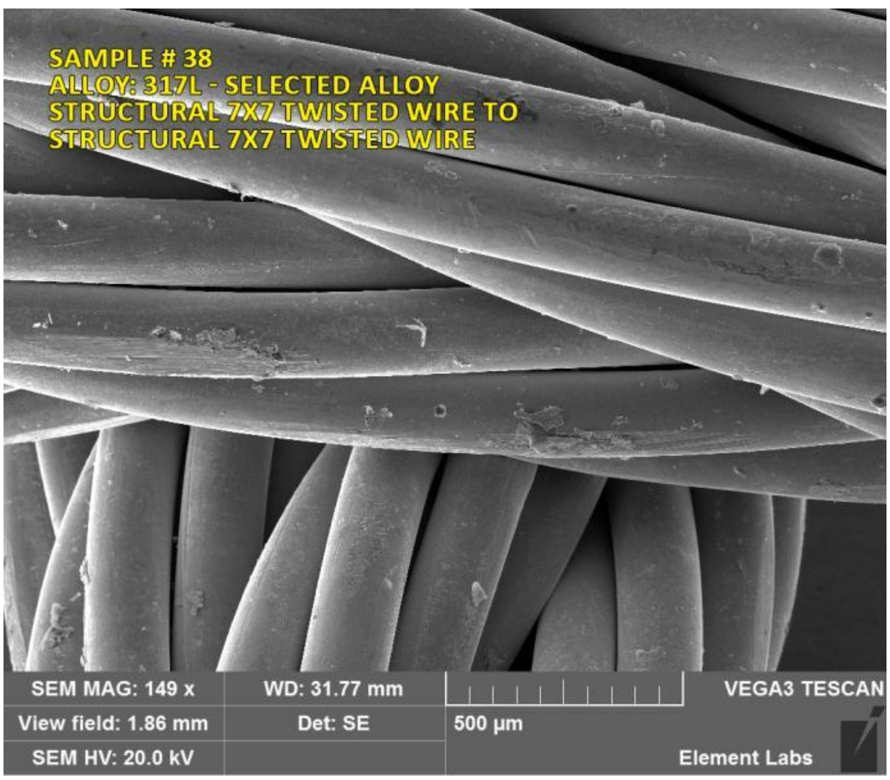
SEM images showing Sample #122 after tensile testing (breaking load = 13 lbs). Pitting was observed on the 316L structural 7x7 twisted wire as shown in the next pair of images.



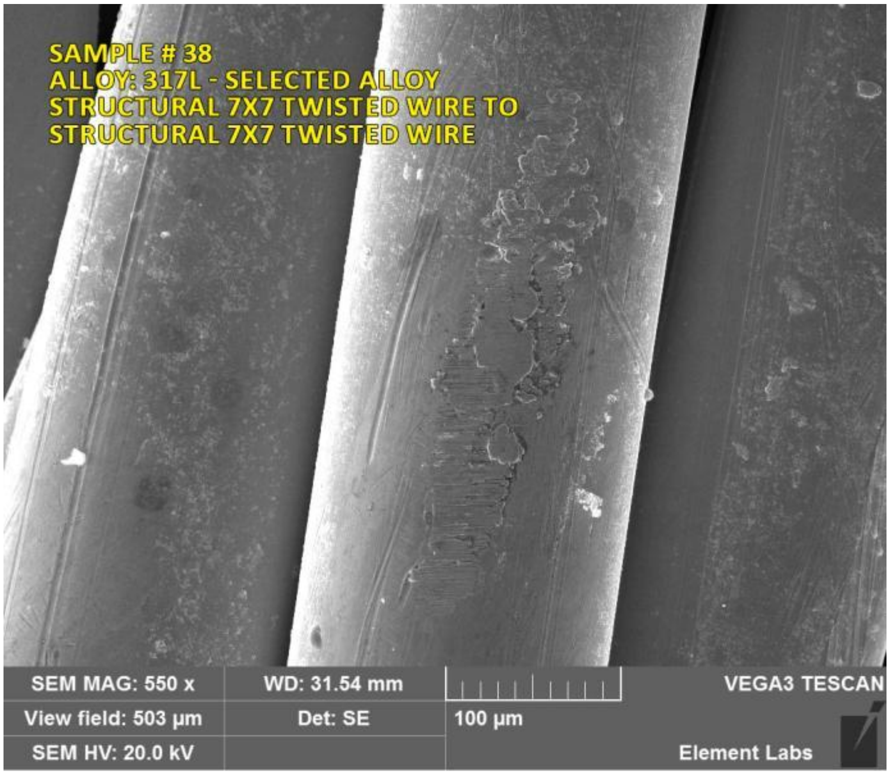


SEM images showing the pitting corrosion from the 316L structural 7x7 twisted wire from Sample # 122.

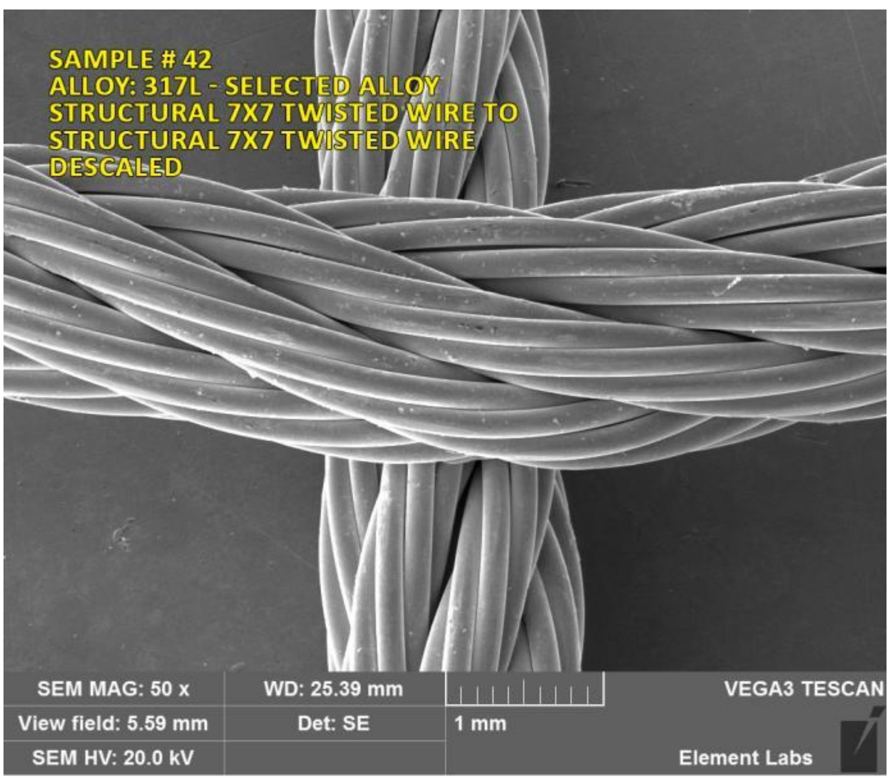




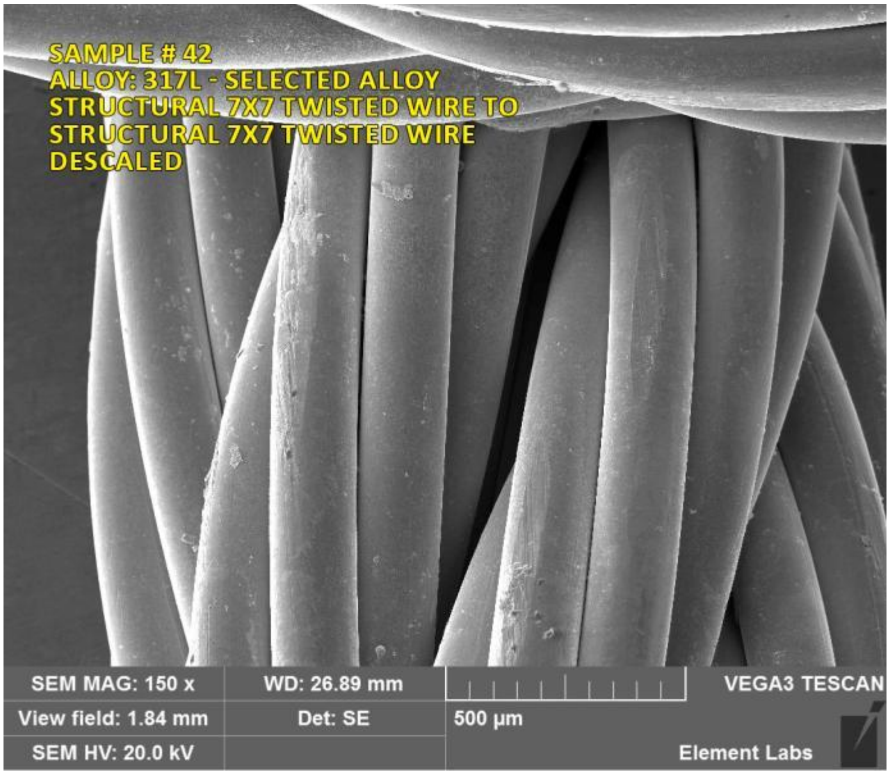
SEM images showing the weld joint from alloy 317L Sample #38. No pits were observed.

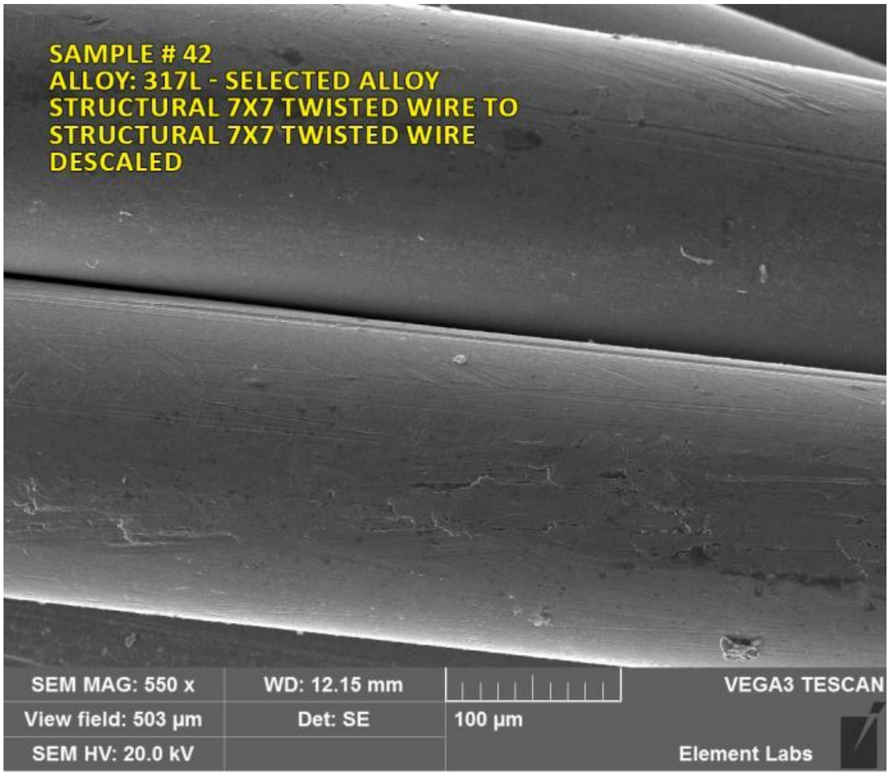


SEM image showing the wires adjacent to the weld of Sample #38. No pits were observed.

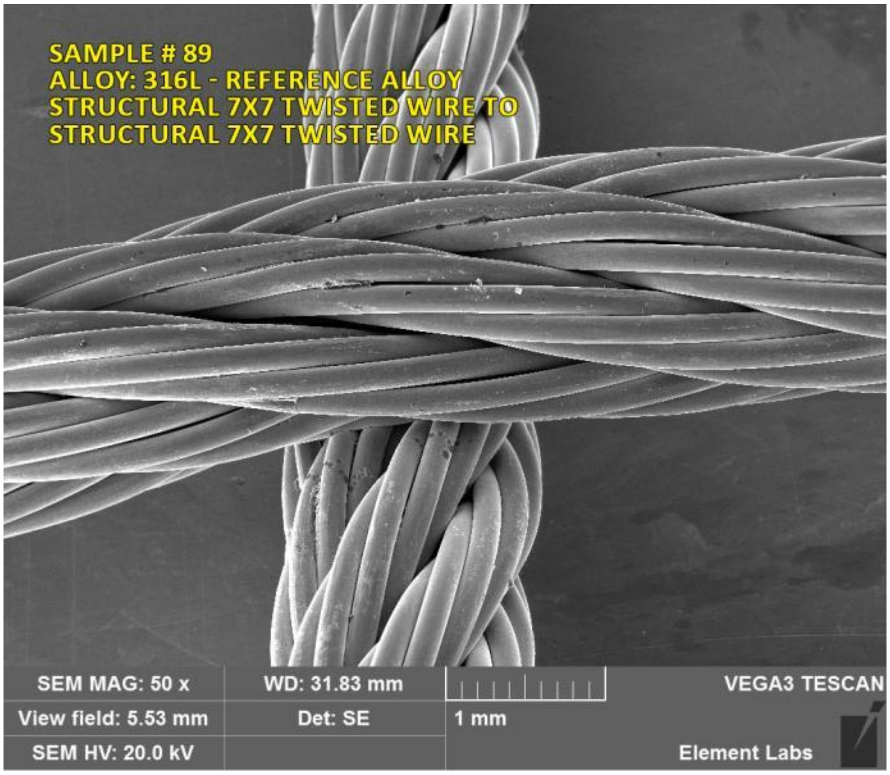


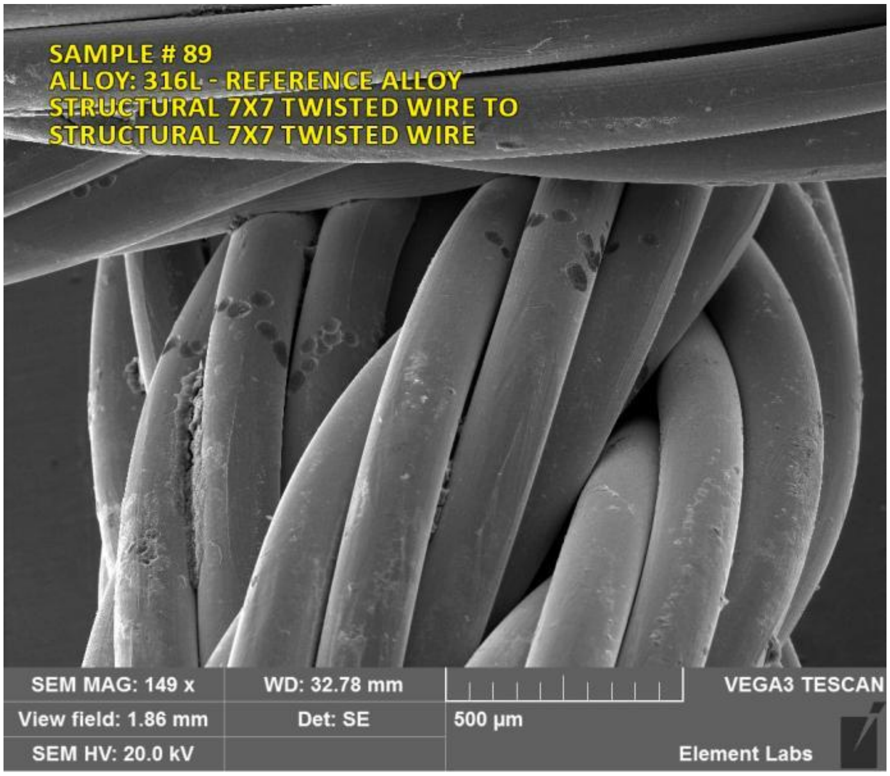
SEM image showing the weld joint from alloy 317L Sample #42. No pits were observed.



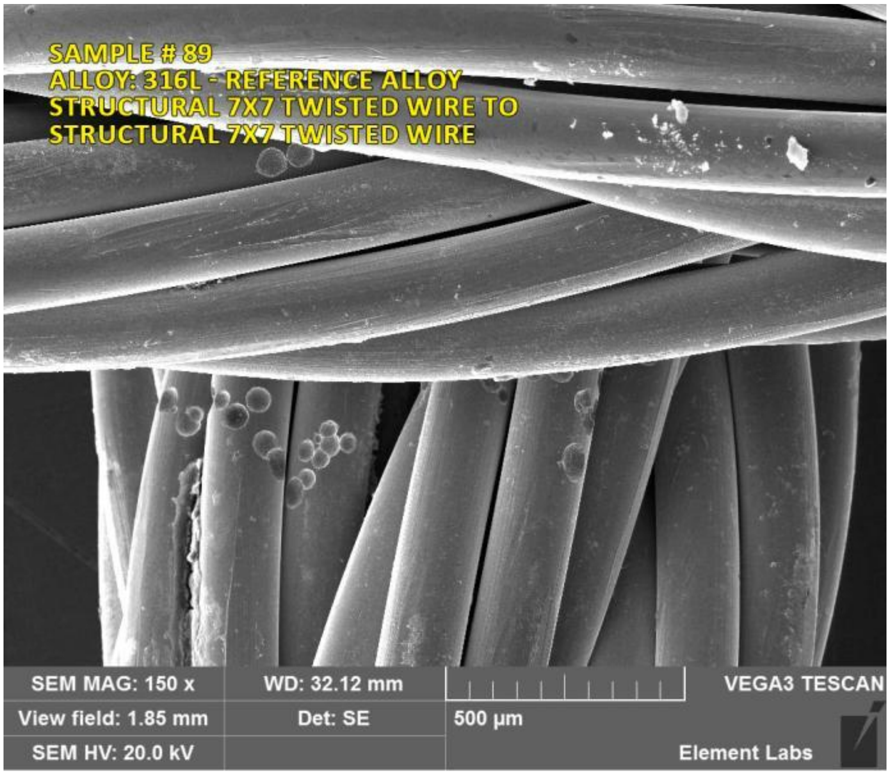


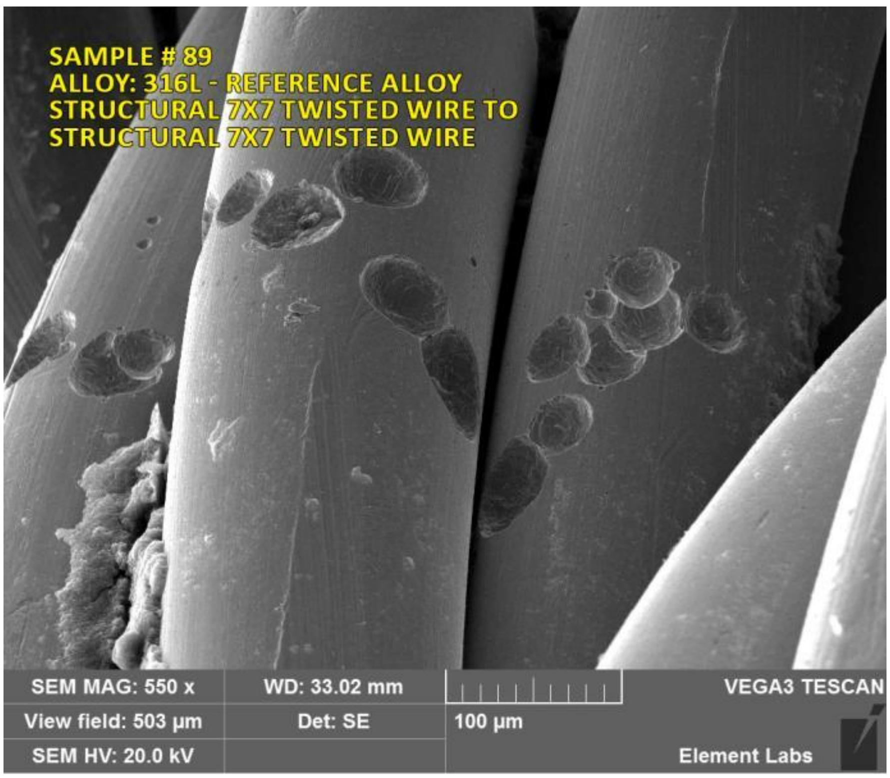
SEM images showing various wires from adjacent to the weld joint from alloy 317L Sample #42. No pits were observed.



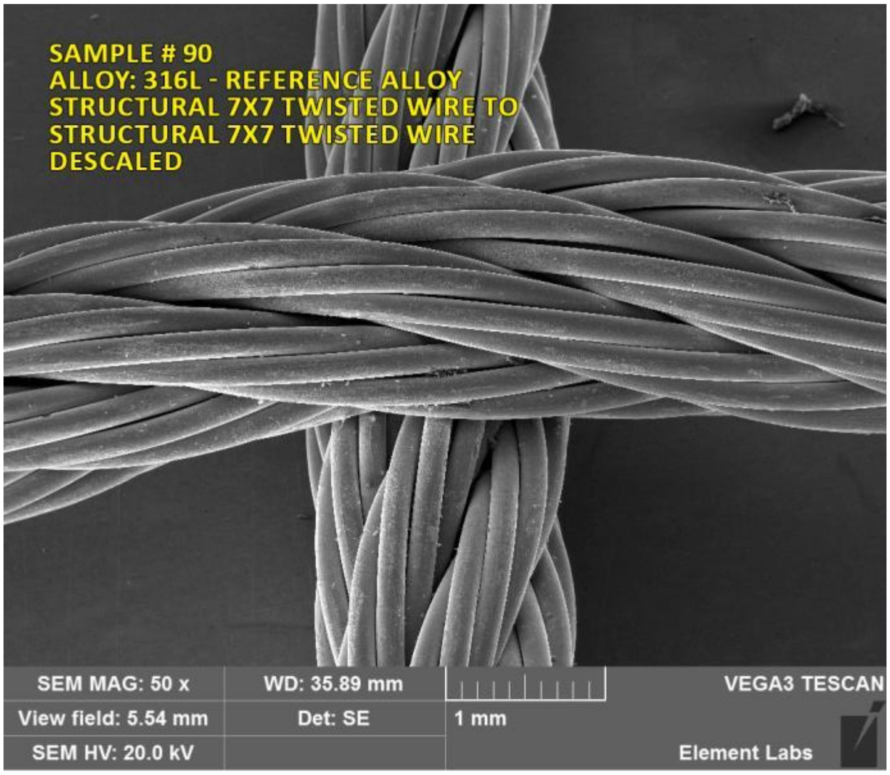


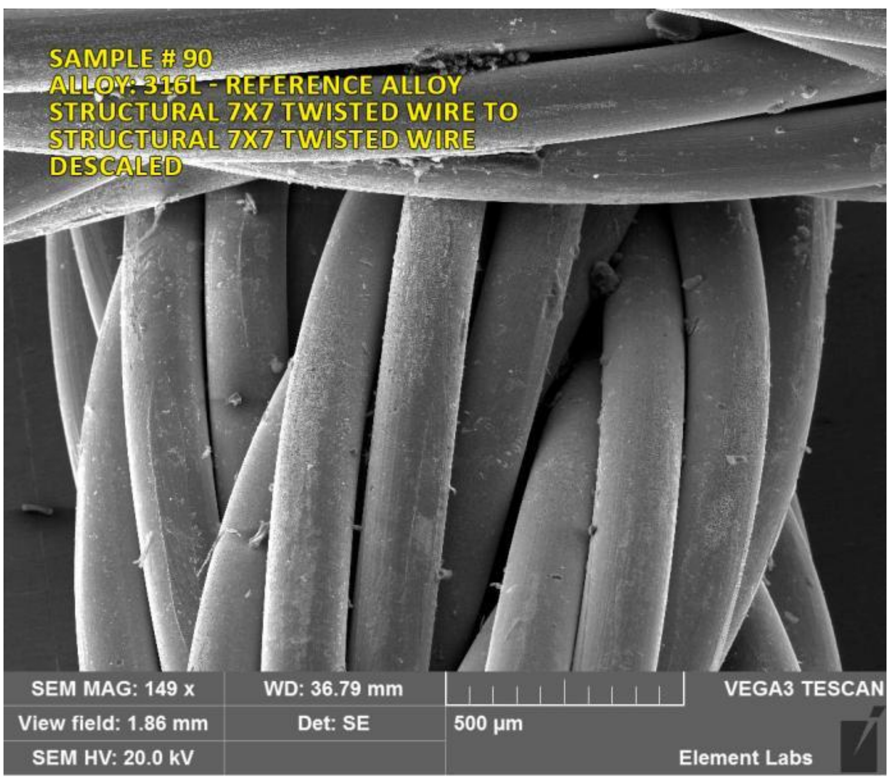
SEM images showing pitting corrosion from the 316L structural 7x7 twisted wire from Sample #89.



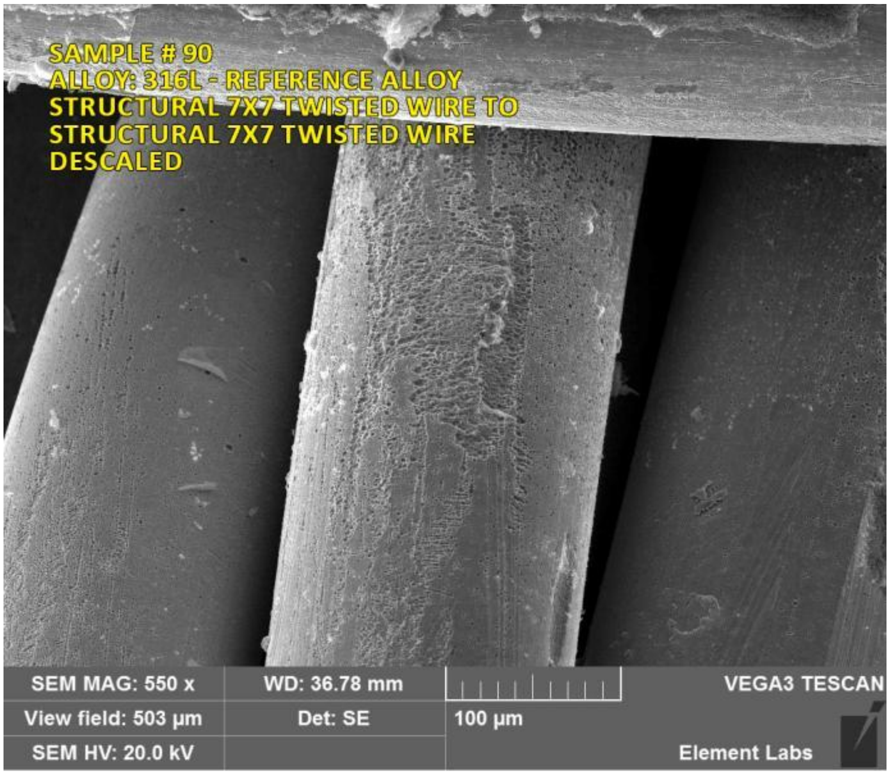


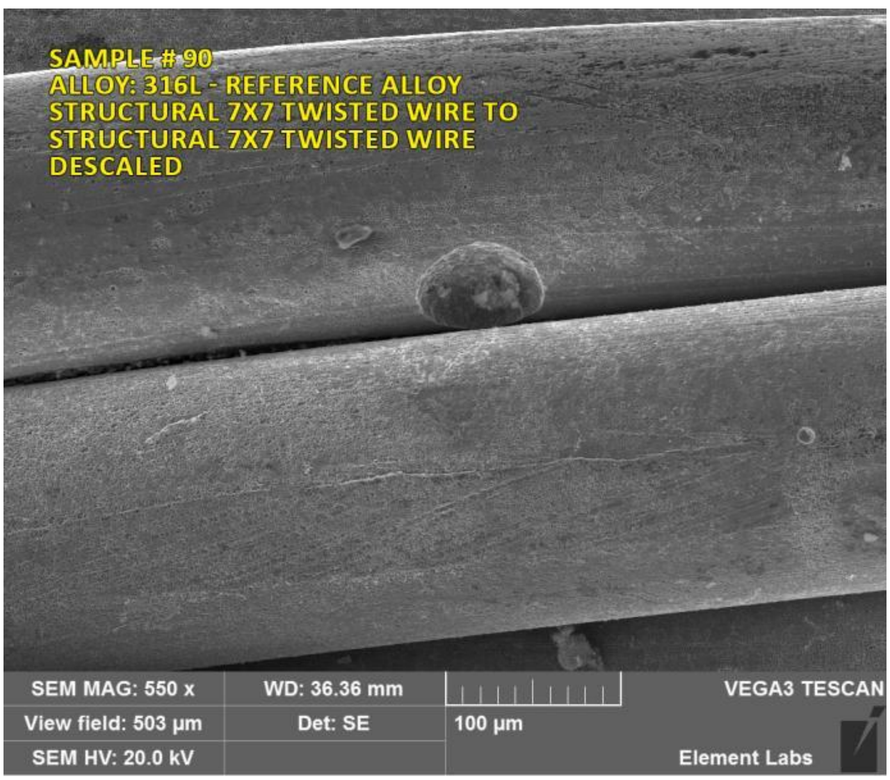
Higher magnification SEM images showing pitting corrosion from the 316L structural 7x7 twisted wire from Sample #89.



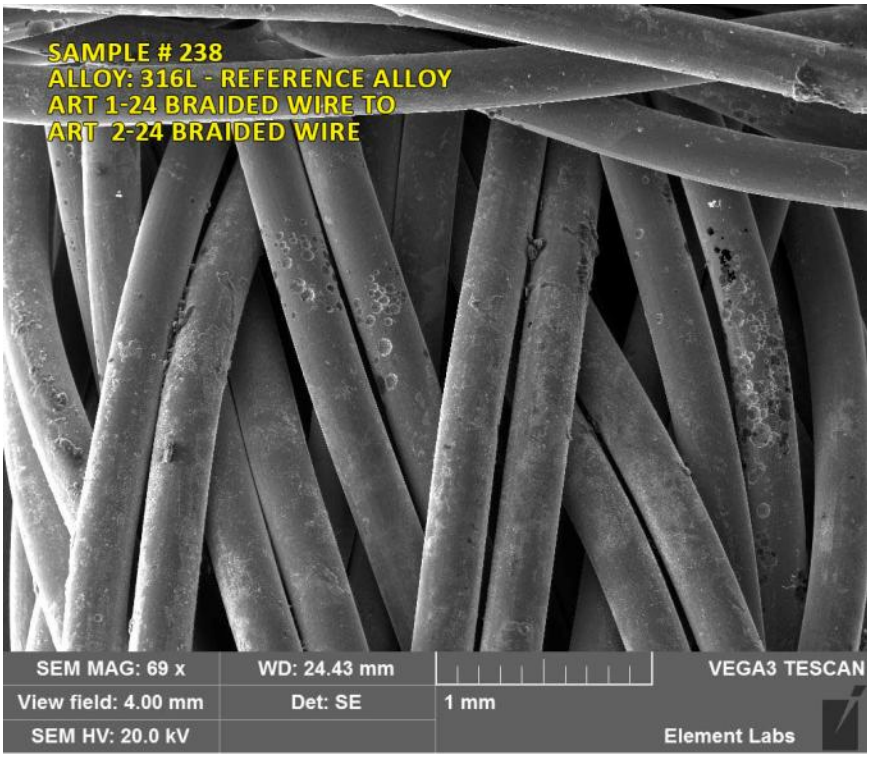


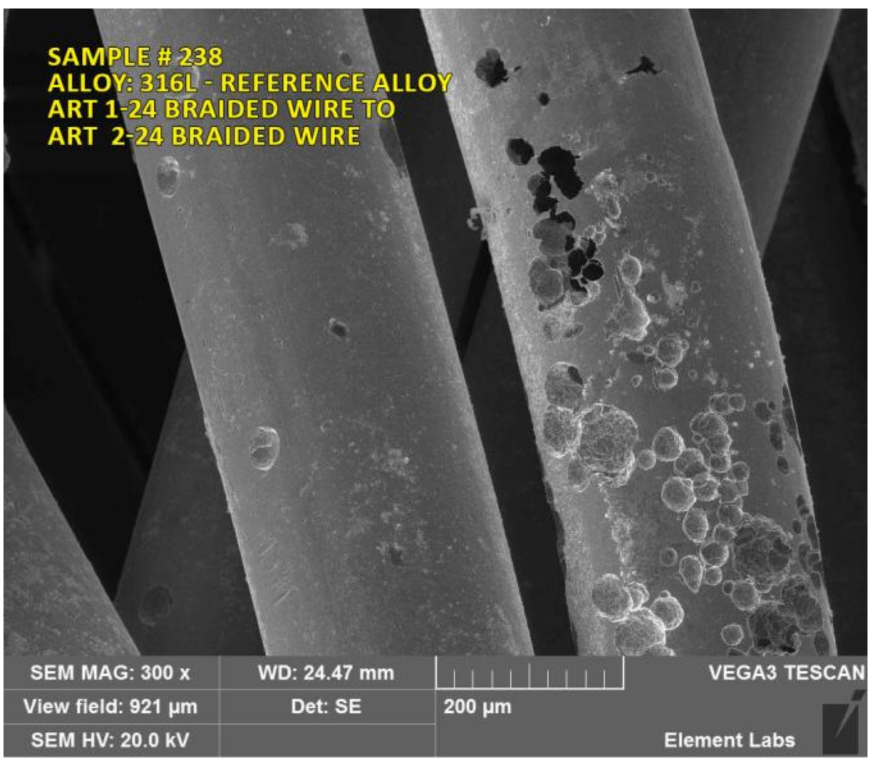
SEM images showing the wire surfaces from alloy 316L Sample # 90 which was descaled, passivated and corrosion tested.





SEM images showing the wire surfaces from alloy 316L Sample # 90 which was descaled, passivated and corrosion tested.





SEM images showing the wire surfaces from alloy 316L Sample # 238 which was corrosion tested. This sample exhibited the most severe pitting attack of the 316L samples examined.

APPENDIX A1 – REFERENCE DIGITAL ELECTRON MICROSCOPE IMAGES

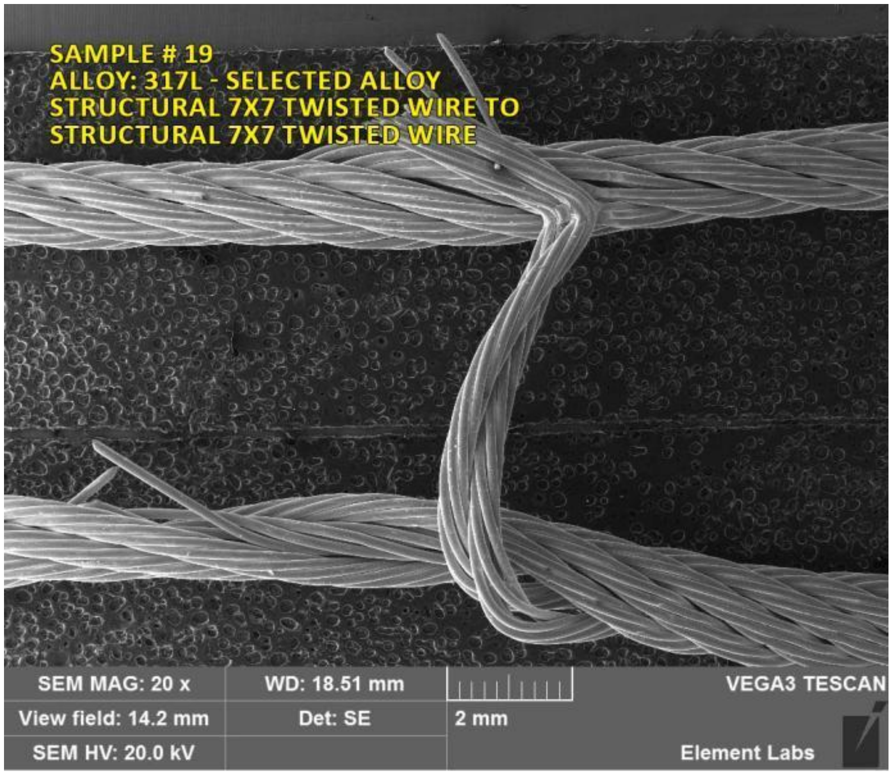
The electron microscope photographs contained in this section of the report represent select samples which were mechanical strength tested following the 1000 hour SO_2 salt spray (fog) corrosion test.

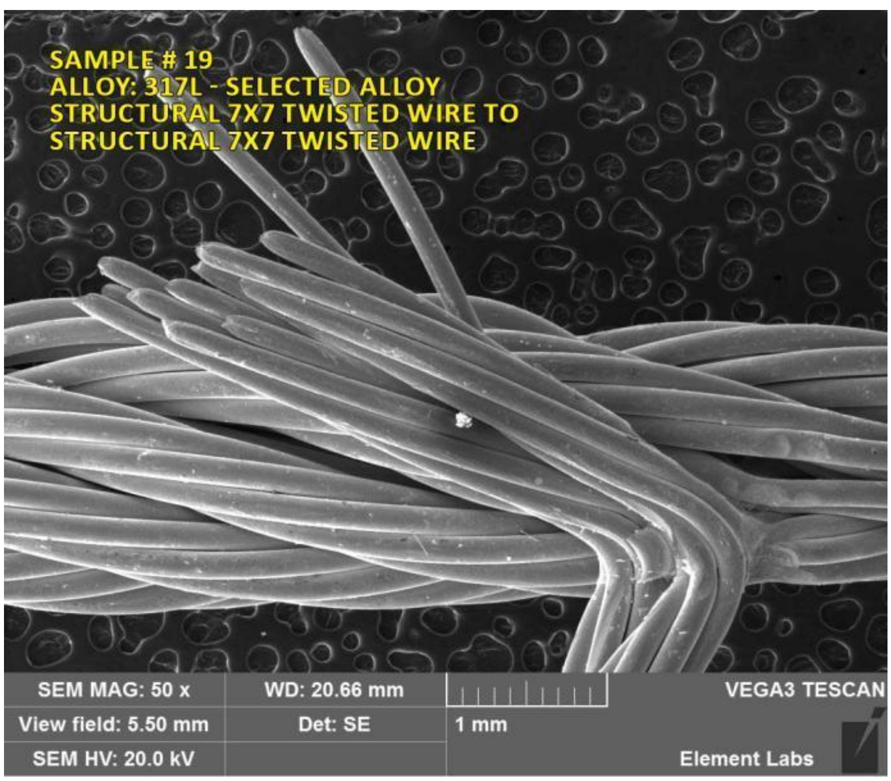
None of the alloy 317L samples showed evidence of pitting. None of the wire breaks from the strength tested alloy 317L samples were associated with pitting.

An example of pitting attack from one of the alloy 316L corrosion and mechanical strength tested samples is presented.

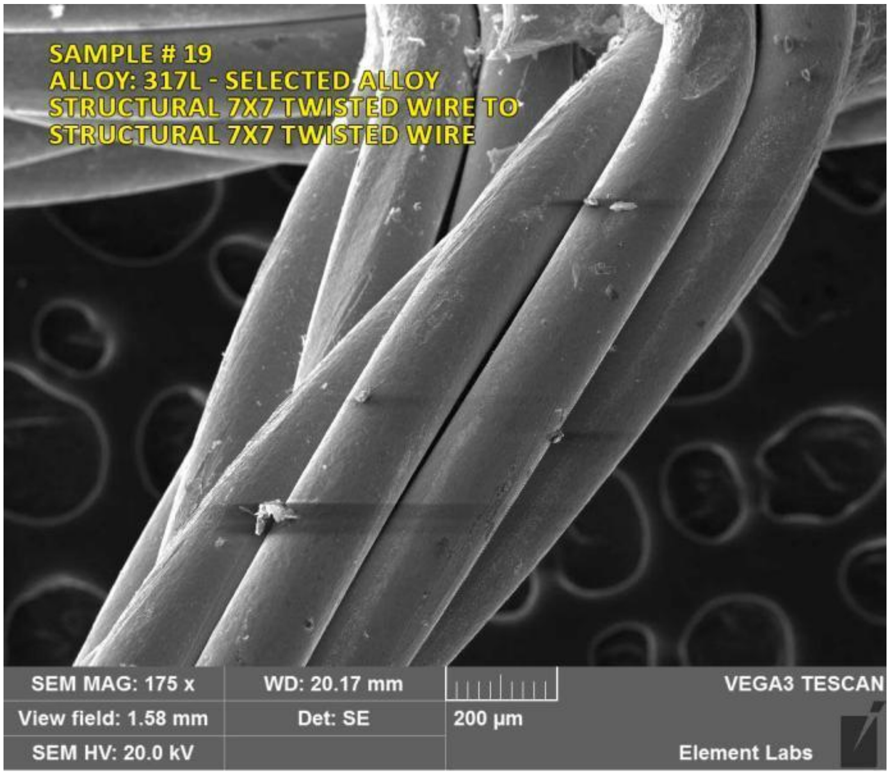
All of the electron microscope images are annotated to reflect the sample # from the Weld Strength Environmental Sample Matrix along with the alloy and wire or braid alloy.

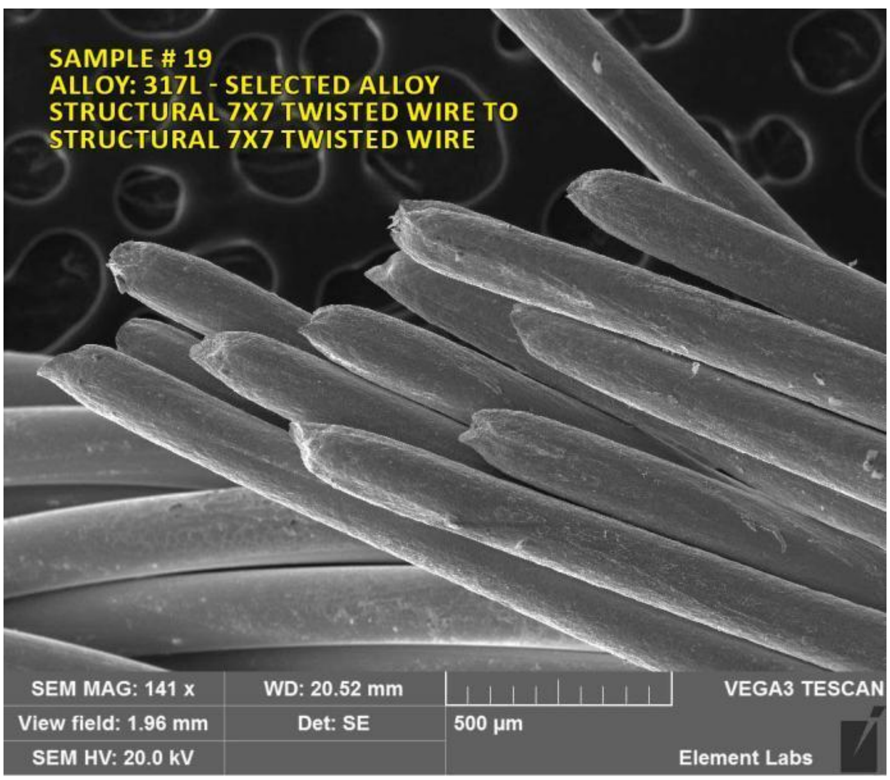
None of the weld joints examined showed obvious evidence of broken wires that could be attributed to corrosion pitting or corrosion related cracking mechanisms.



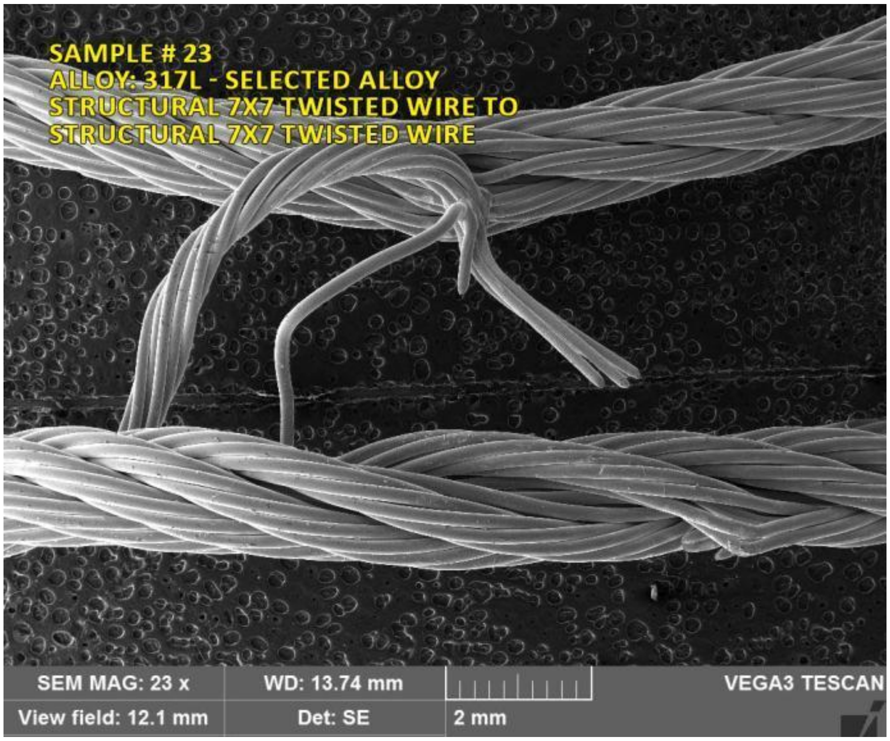


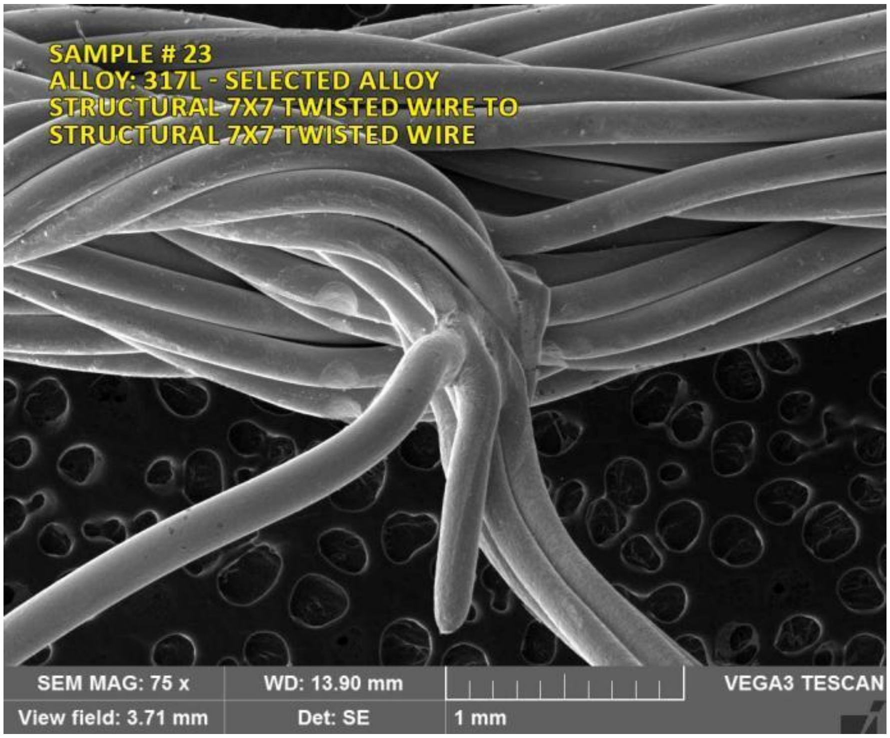
SEM micrograph showing Sample #19 after corrosion and mechanical strength testing. Note that the fracture did not occur at the weld and that two strands are still attached between the structural members.



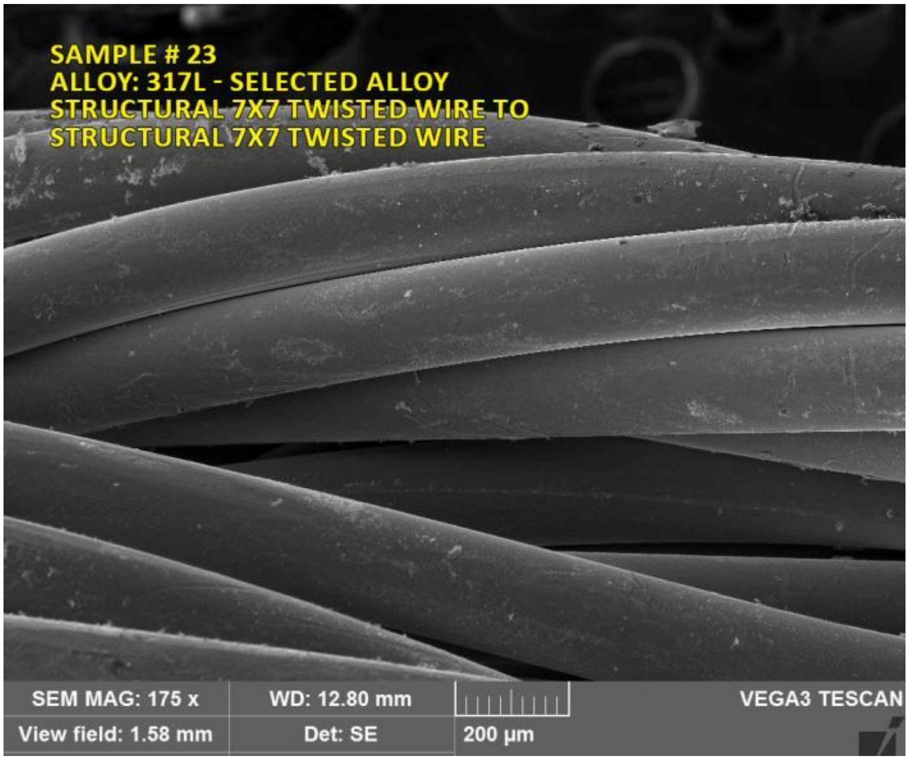


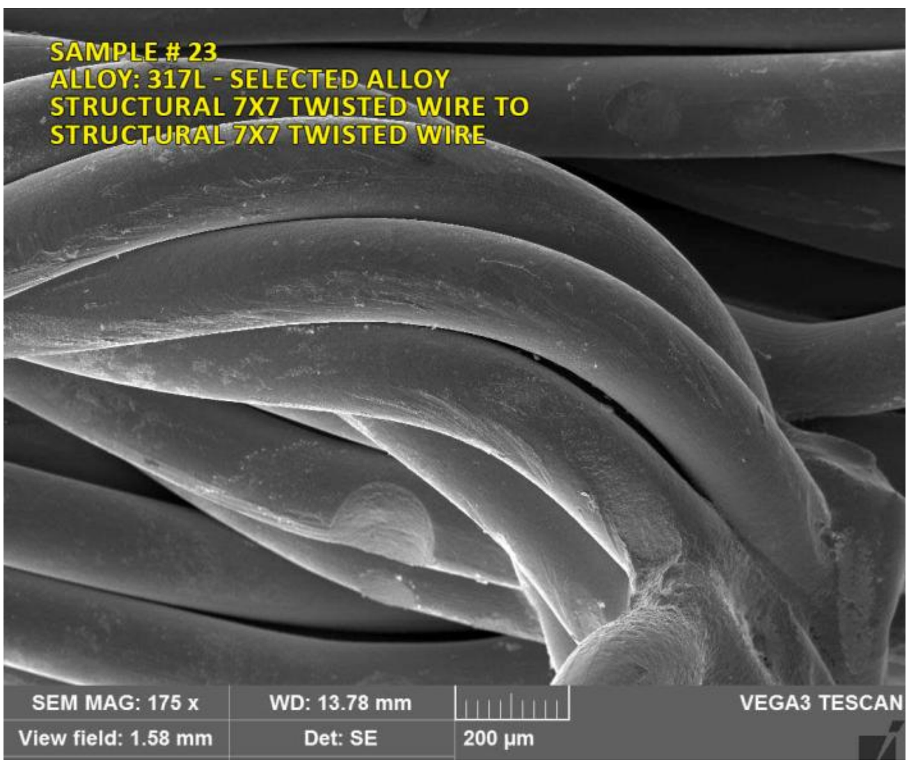
SEM micrographs (Sample #19) showing the no evidence of pitting on the wires adjacent to the weld (upper image) and the ductile nature of the wire fractures (lower image).



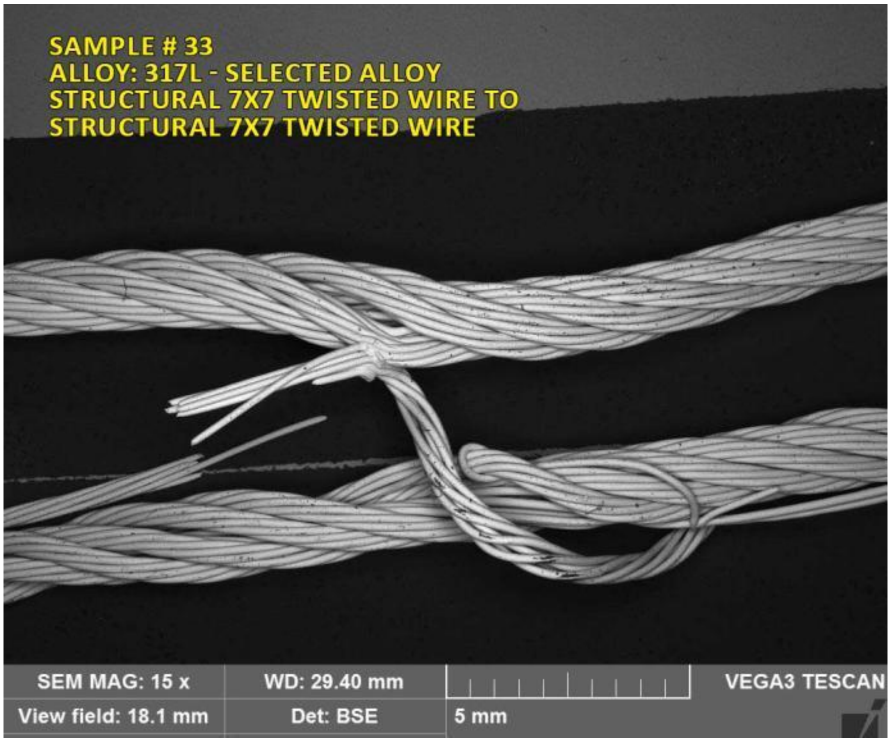


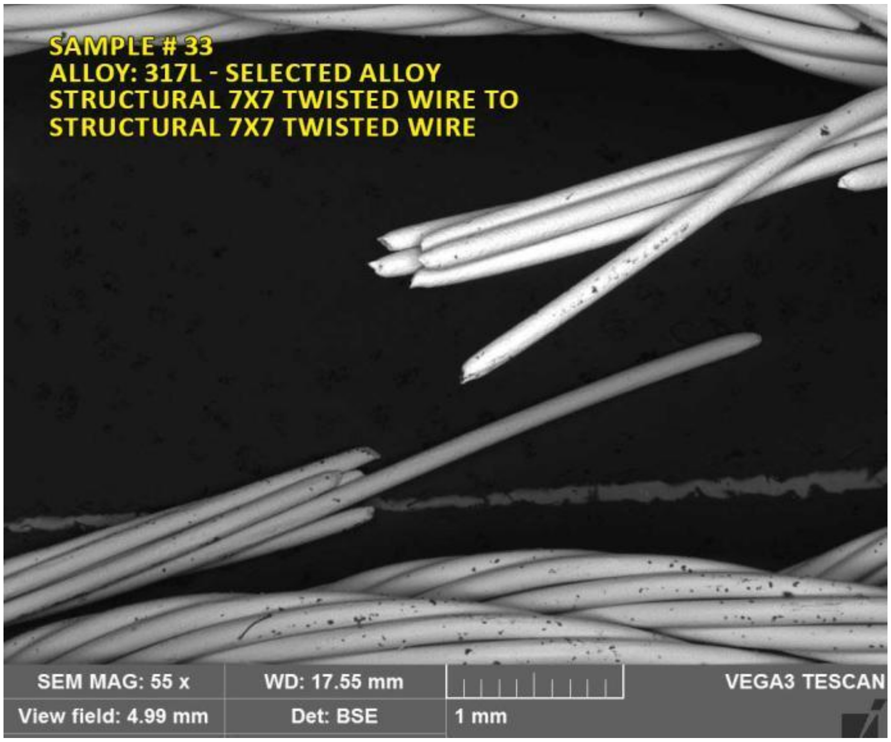
SEM micrograph showing Sample #23 after corrosion and mechanical strength testing. Note that the majority of the fractures occurred away from the weld and that one strand is still attached between the structural members. No evidence of pitting attack is visible.



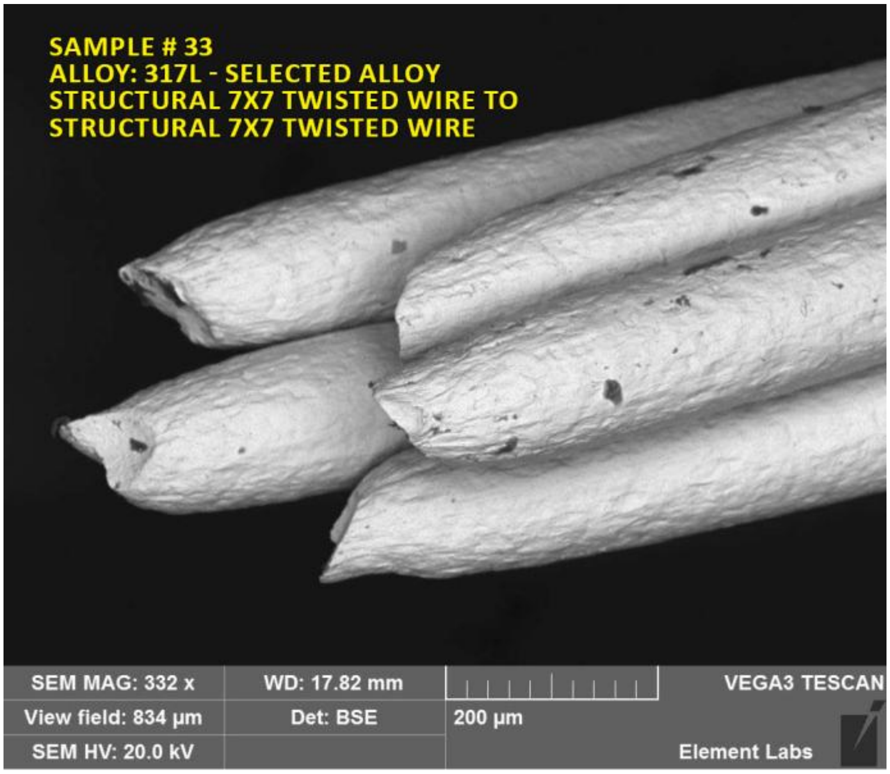


SEM micrographs showing wires from Sample #23 after corrosion and mechanical strength testing. No evidence of pitting was observed.

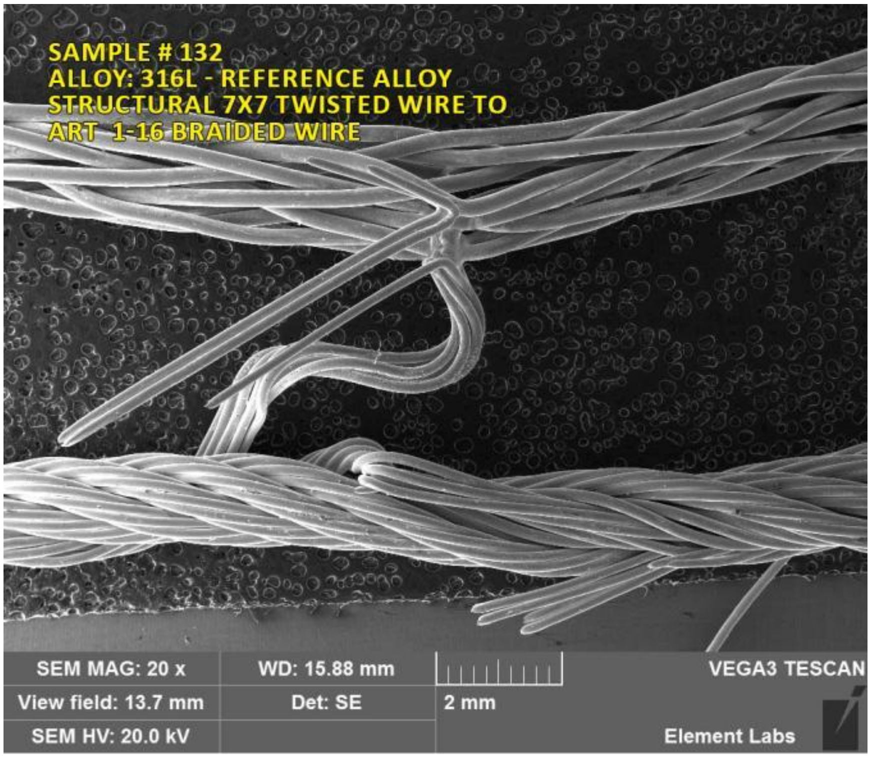


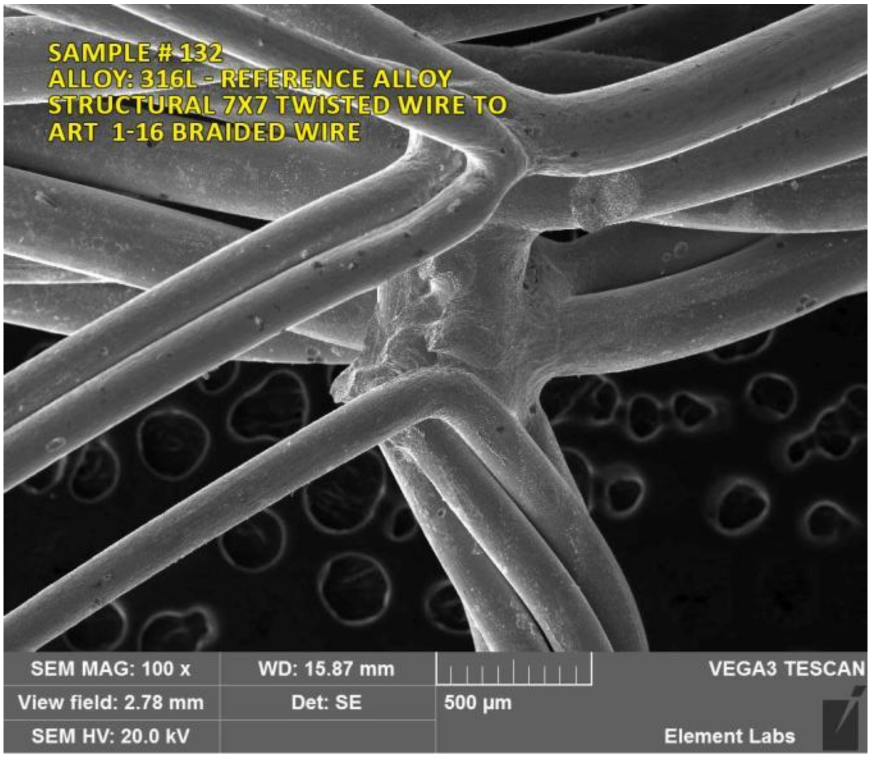


SEM micrograph showing Sample #33 after corrosion testing and mechanical strength testing. Note that the majority of the fractures occurred away from the weld and that one strand is still attached between the structural members.

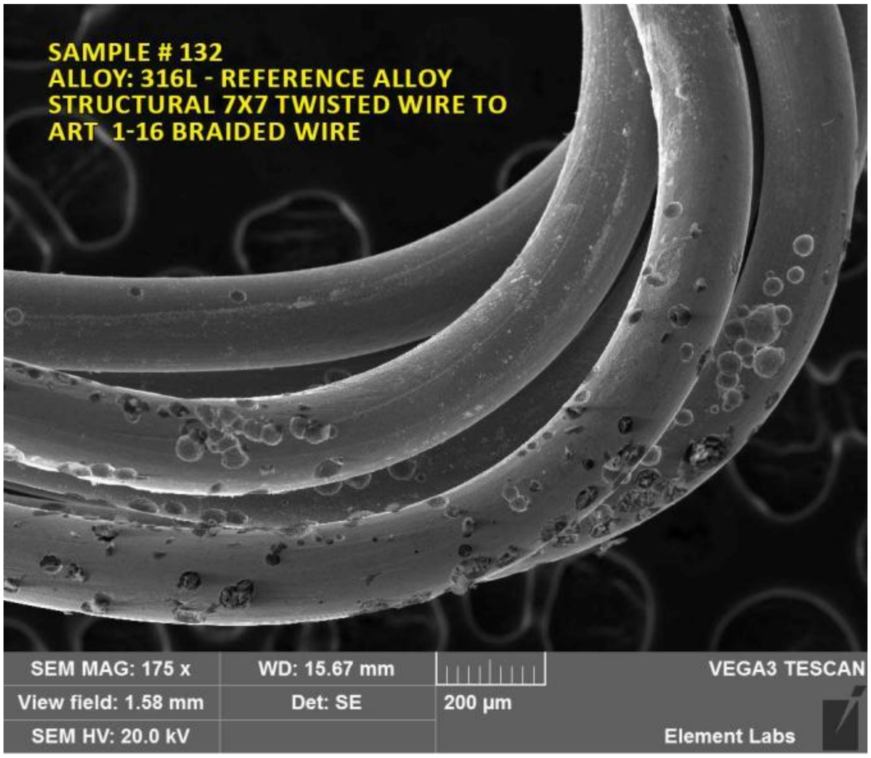


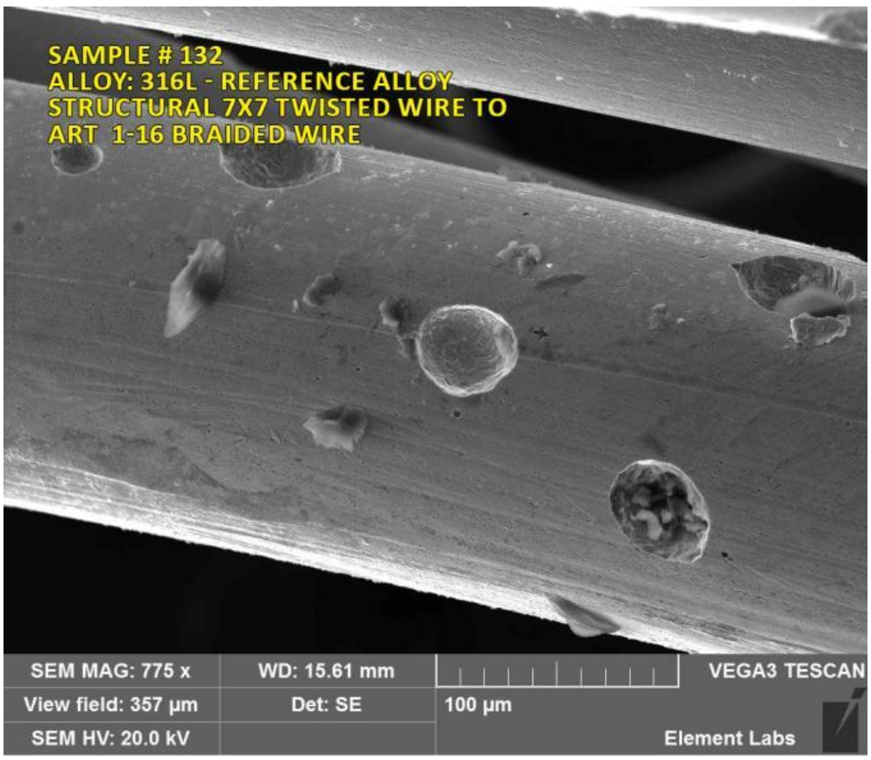
SEM micrograph showing ductile nature of the wire fractures from Sample #33. No evidence of pitting damage is visible on the alloy 317L twisted wire.





SEM images of Sample #132 (alloy 316L) after corrosion testing and mechanical strength testing. Evidence of pitting attack was observed as shown in the following images.





Higher magnification SEM images of Sample # 132 (316L) after corrosion testing and mechanical strength testing. Obvious evidence of pitting damage to the individual wires is visible.

APPENDIX A2 – REFERENCE DIGITAL MICROSCOPE PHOTOGRAPHS

The photographs contained in this section of the report represent the SO_2 salt spray tested samples identified in the Weld Strength Environmental Sample Matrix which were left intact and designated as inspect and photo document.

In most cases several photographs are included for each sample. The photographs represent an overall image or view of the weld joint location although the weld itself is not visible because it exists in the interface between the two braids. Additional photographs of the wires away from the weld are also presented in order to illustrate the excellent condition of the wires following the 1000 hour acidified SO_2 salt spray test.

None of the weld joints examined showed obvious evidence of broken wires that could be attributed to corrosion pitting or corrosion related cracking mechanisms.

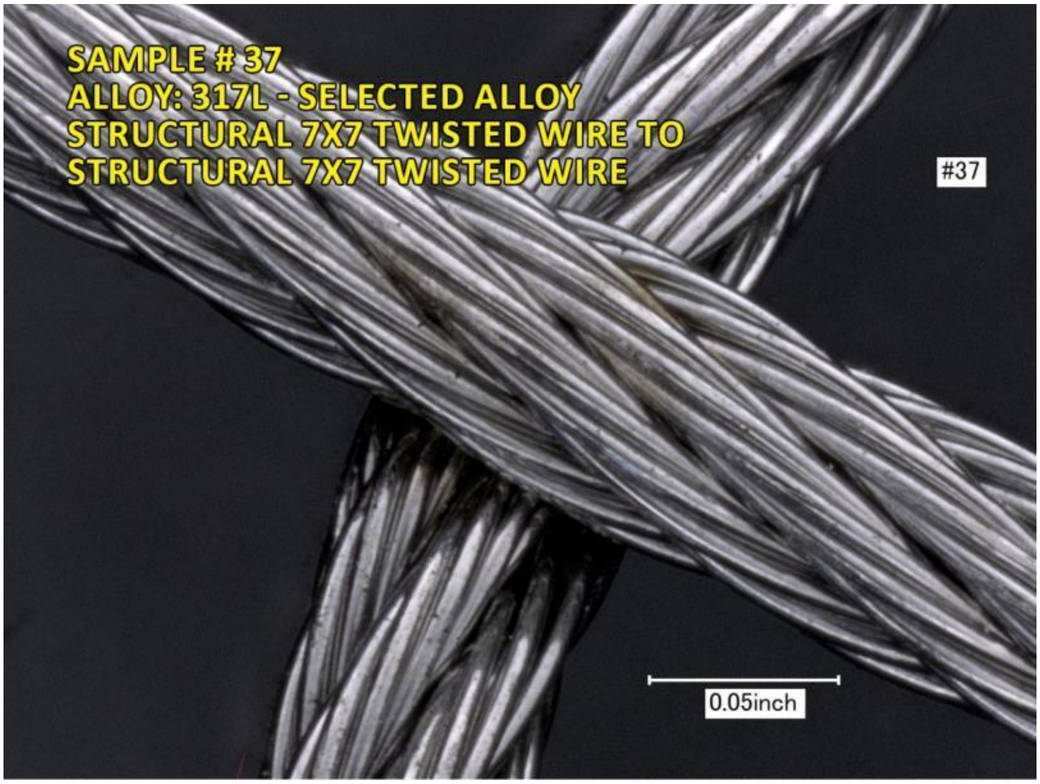
None of the samples examined showed evidence of red rusting and associated streaking.

Almost all of the photographs show black spots which represent residual carbon black that had been applied to the welded wire joints prior to salt spray testing in order to simulate the accumulation of atmospheric deposits.

Heat tint colors (oxidation tints) are visible on several, not all of the weld joint photographs.

Pitting attack was observed on several of the alloy 316L welded samples examined. The pitting attack was limited to the immediate vicinity of the weld, typically within 3 to 5 mm from the weld and was generally observed at the interfaces between the two welded braids or wires. This behavior was observed on both the structural and art alloy 316L weld joints. Due to the microscopic nature of the pits themselves they are not visible in the images presented which were taken at magnifications of approximately 12X, 20X and 40X as indicated.

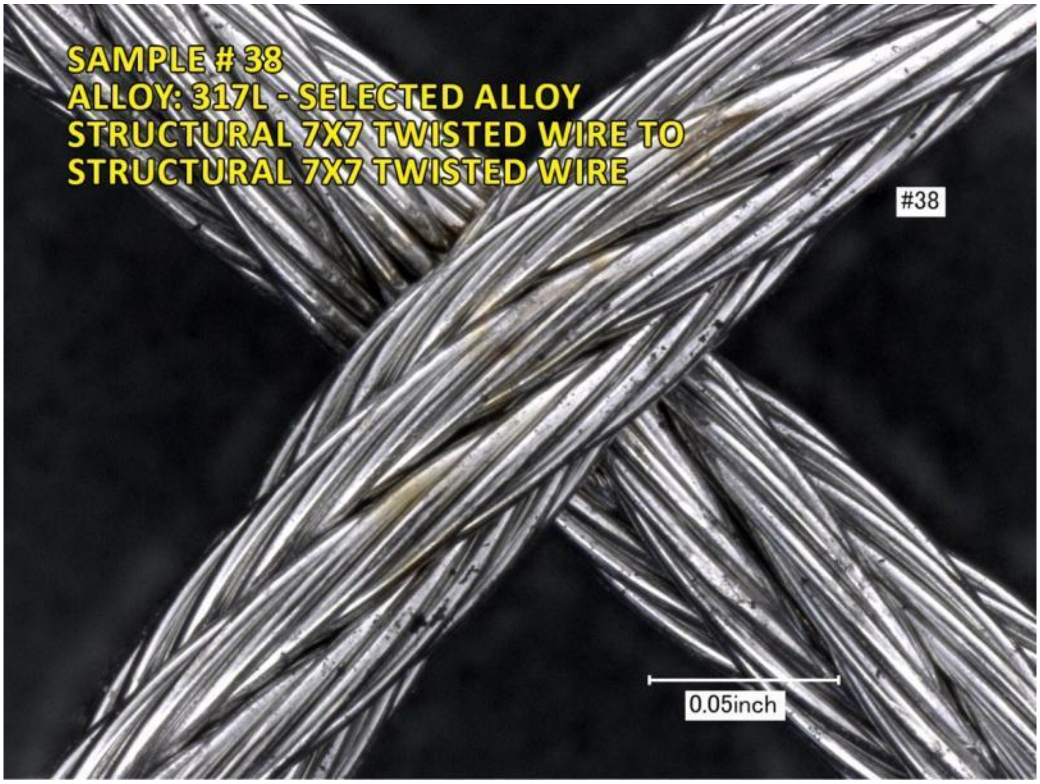
All of the images are annotated to reflect the sample # from the Weld Strength Environmental Sample Matrix along with the alloy and wire types.


SAMPLE # 37
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#37
0.05inch

(~20X)


SAMPLE # 37
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#37
0.050inch

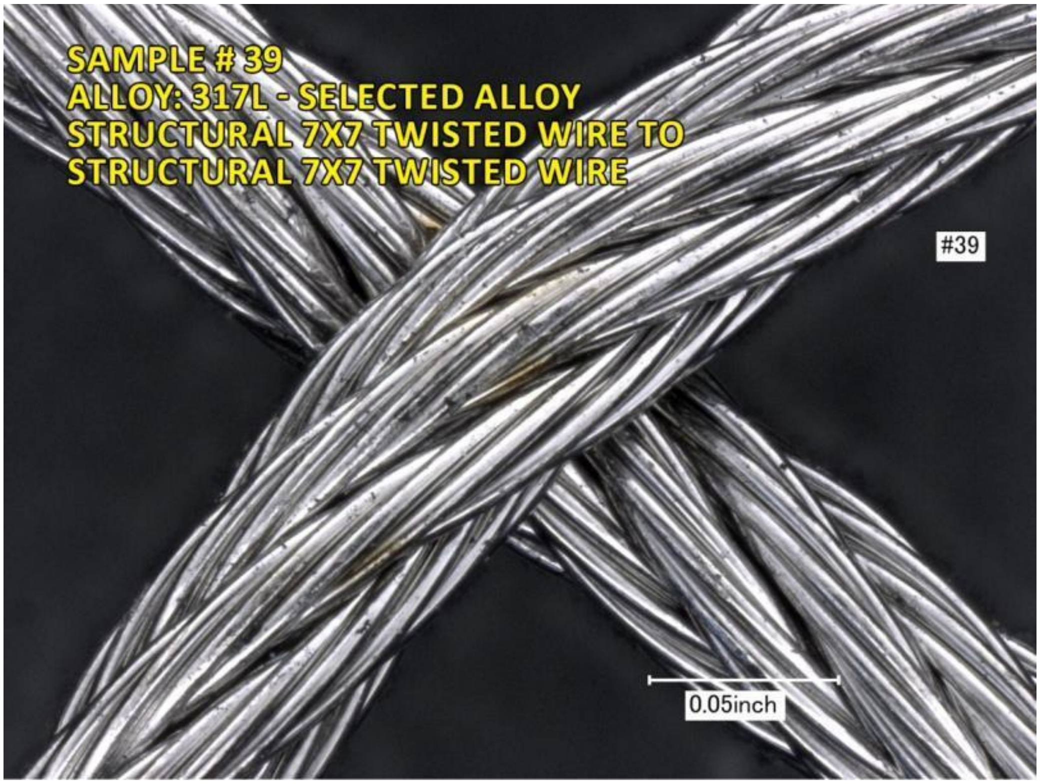
(~40X)


SAMPLE # 38
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#38
0.05inch

(~20X)


SAMPLE # 38
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#38
0.050inch

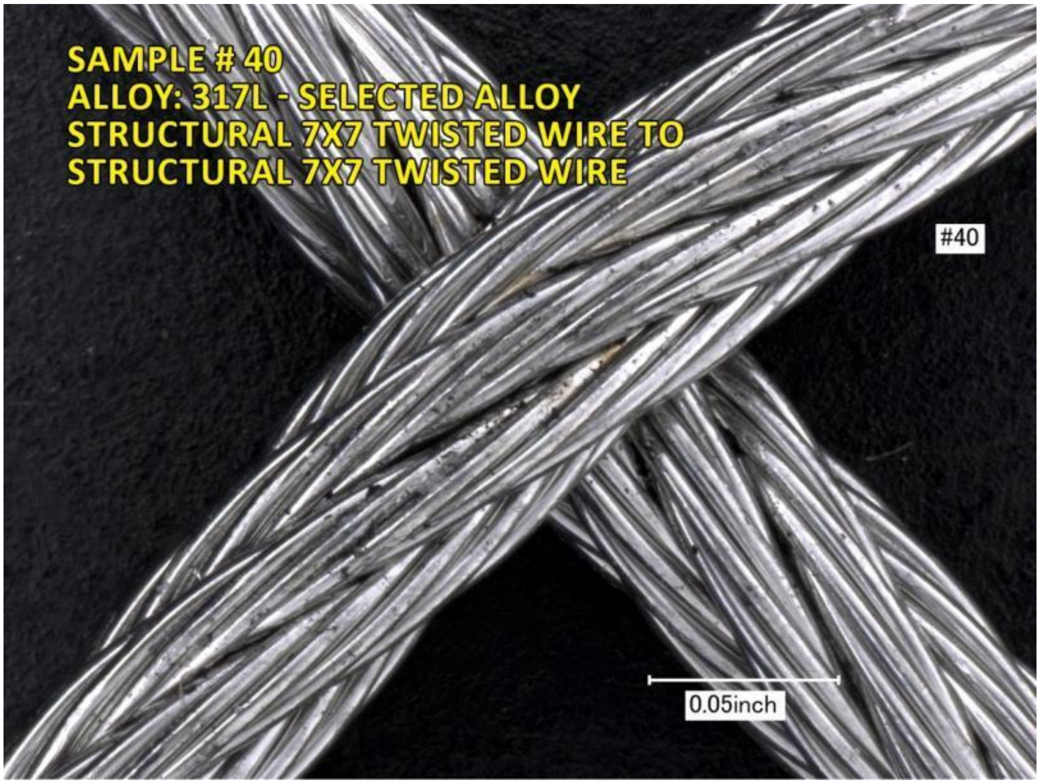
(~40X)


SAMPLE # 39
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#39
0.05inch

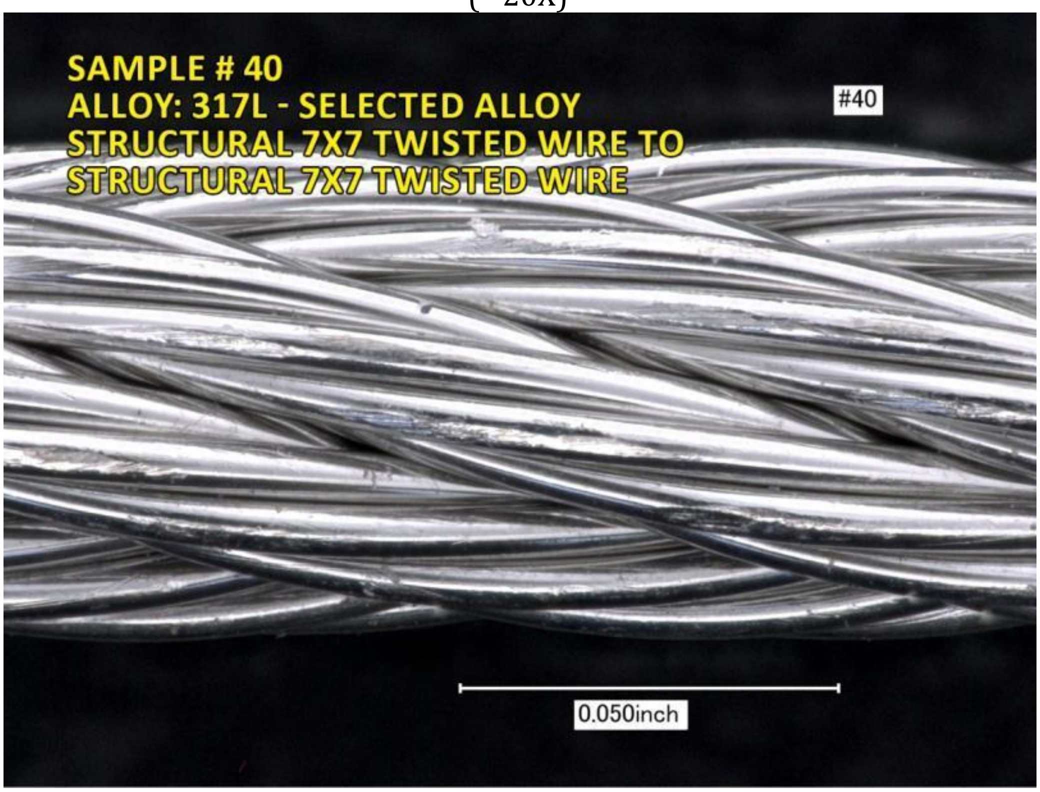
(~20X)


SAMPLE # 39
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#39
0.050inch

(~40X)


SAMPLE # 40
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#40
0.05inch

(~20X)


SAMPLE # 40
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#40
0.050inch

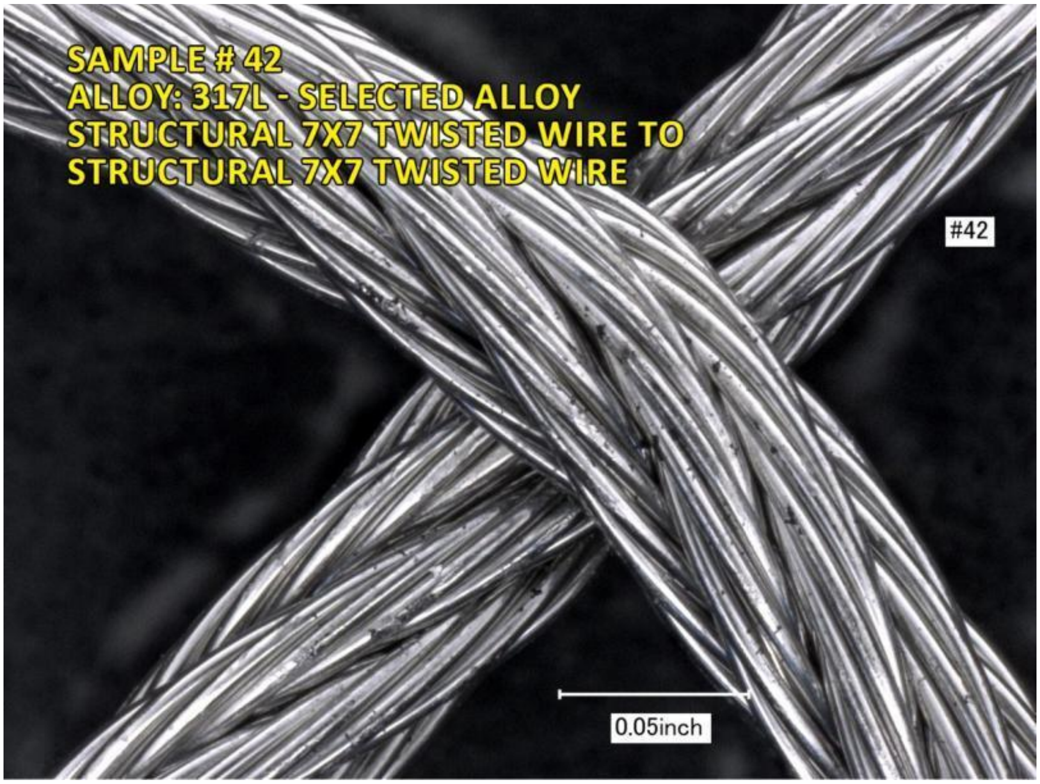
(~40X)


SAMPLE # 41
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#41
0.05inch

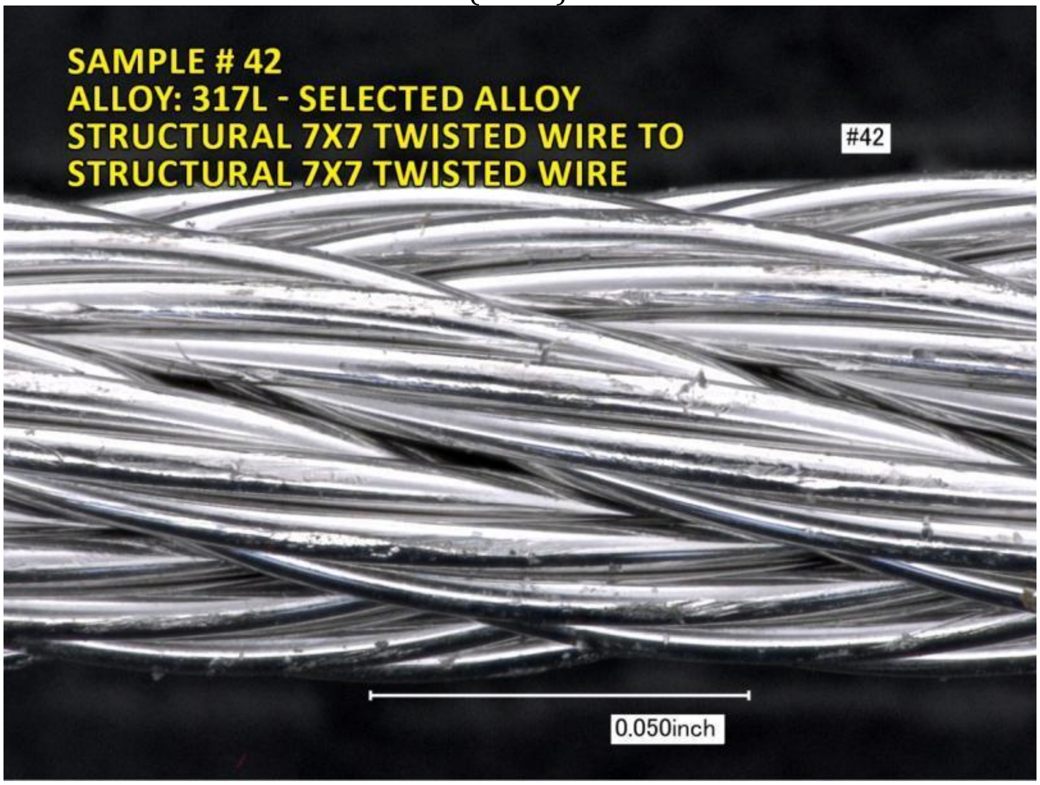
(~20X)


SAMPLE # 41
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#41
0.050inch

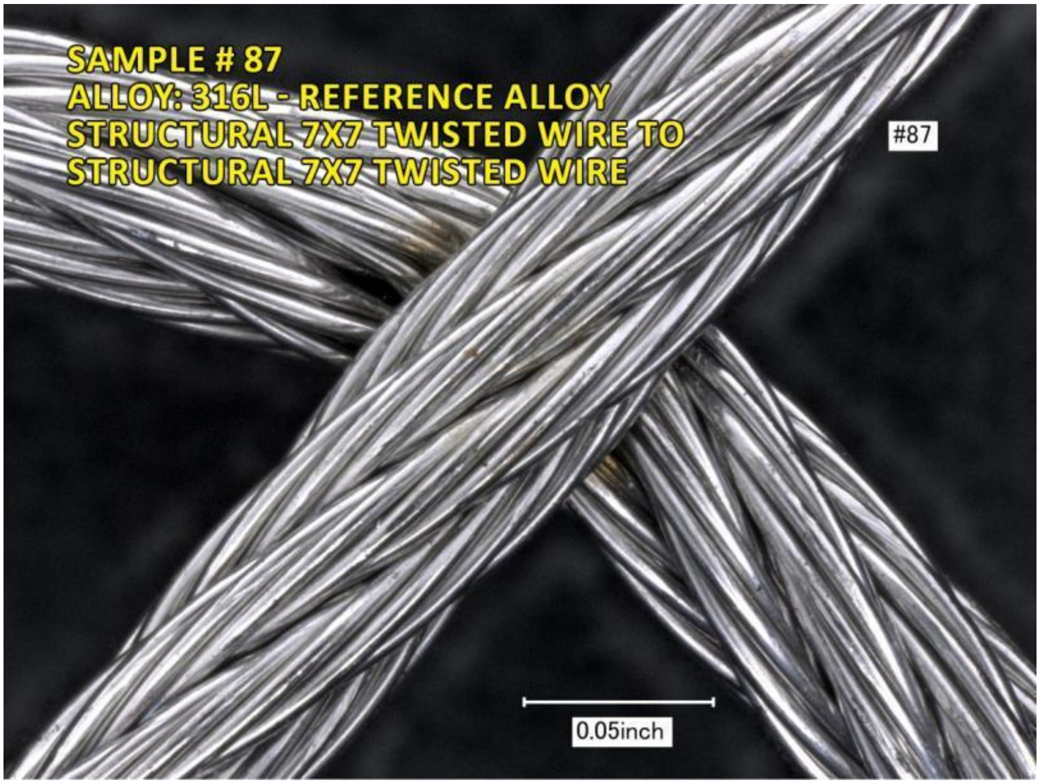
(~40X)


SAMPLE # 42
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#42
0.05inch

(~20X)


SAMPLE # 42
ALLOY: 317L - SELECTED ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#42
0.050inch

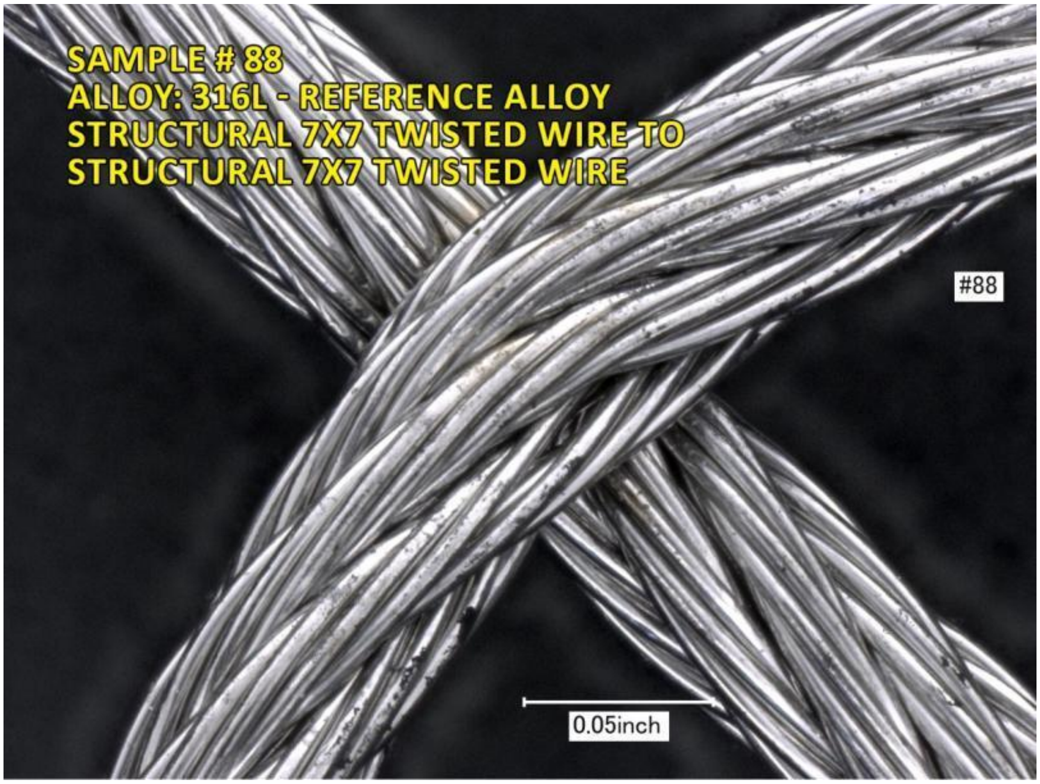
(~40X)


SAMPLE # 87
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#87
0.05inch

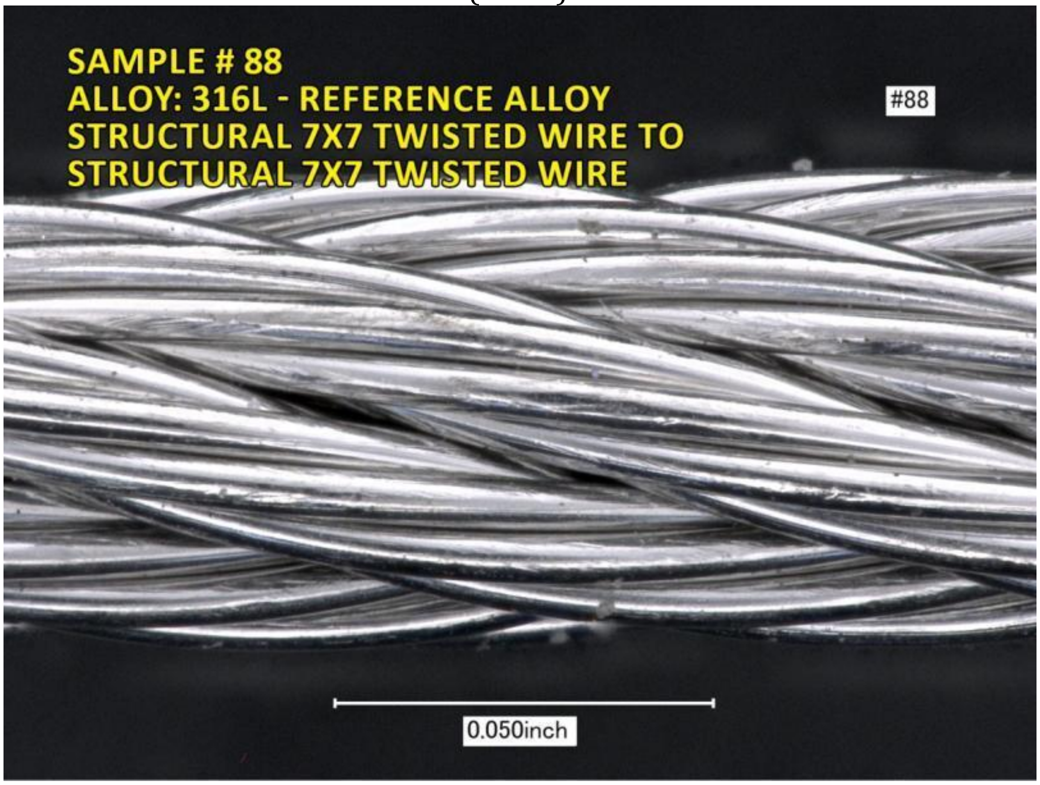
(~20X)


SAMPLE # 87
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#87
0.050inch

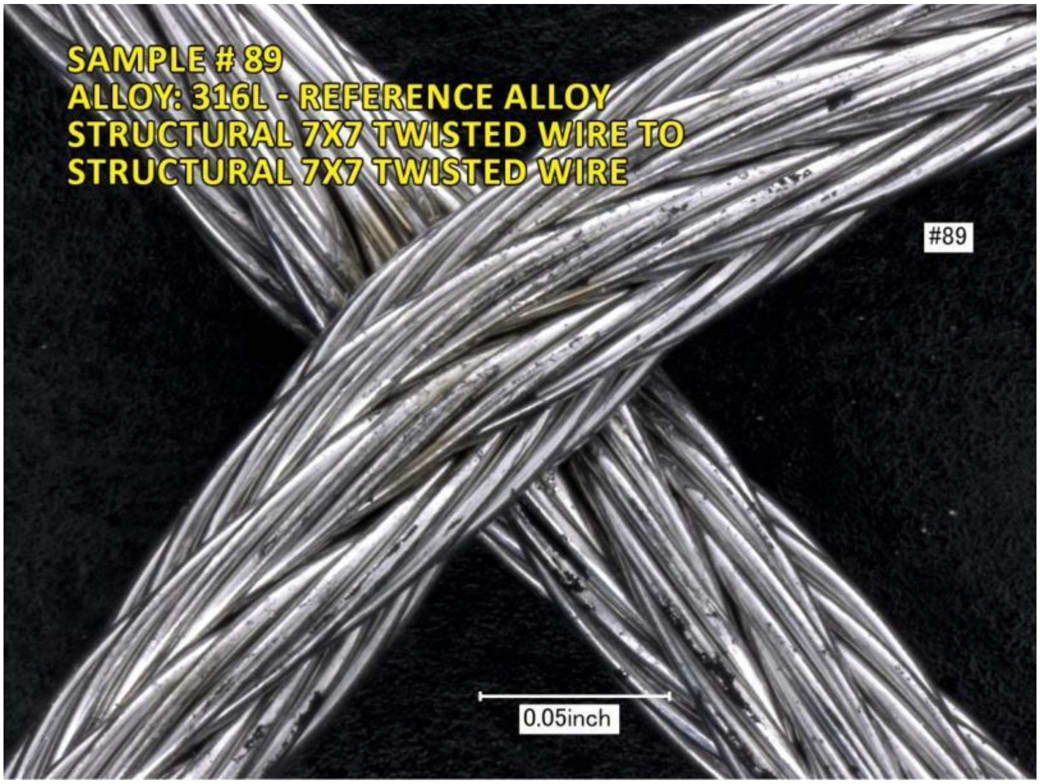
(~40X)


SAMPLE # 88
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#88
0.05inch

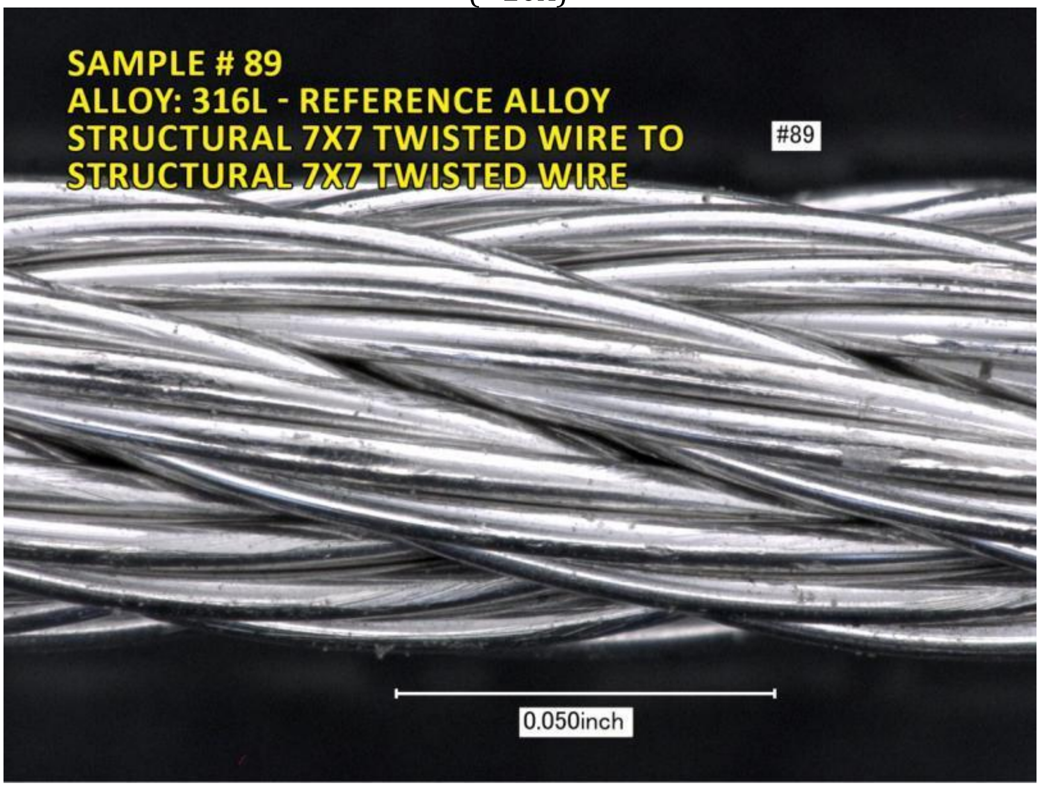
(~20X)


SAMPLE # 88
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#88
0.050inch

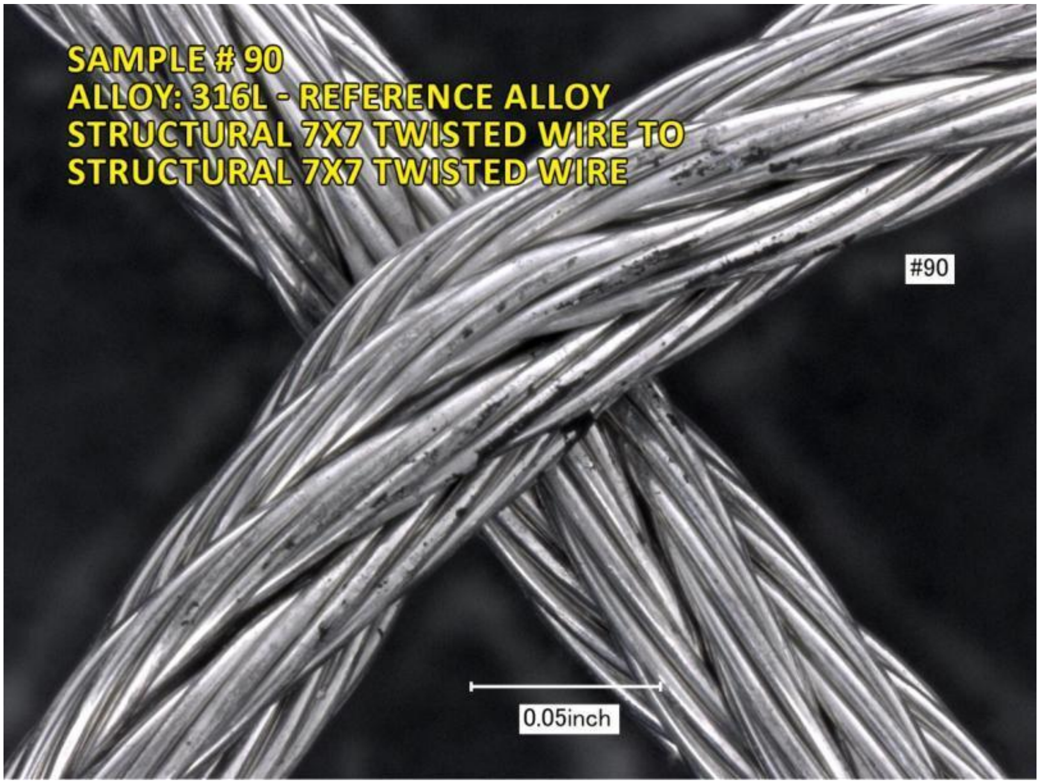
(~40X)


SAMPLE # 89
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#89
0.05inch

(~20X)


SAMPLE # 89
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#89
0.050inch

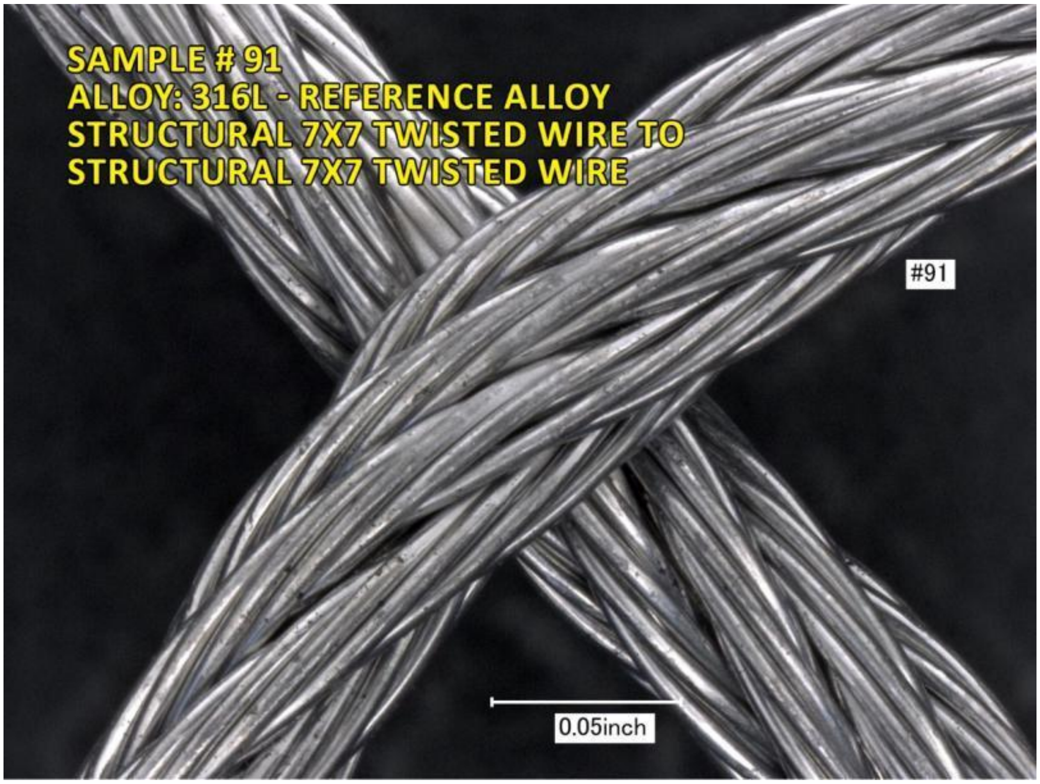
(~40X)


SAMPLE # 90
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#90
0.05inch

(~20X)


SAMPLE # 90
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#90
0.050inch

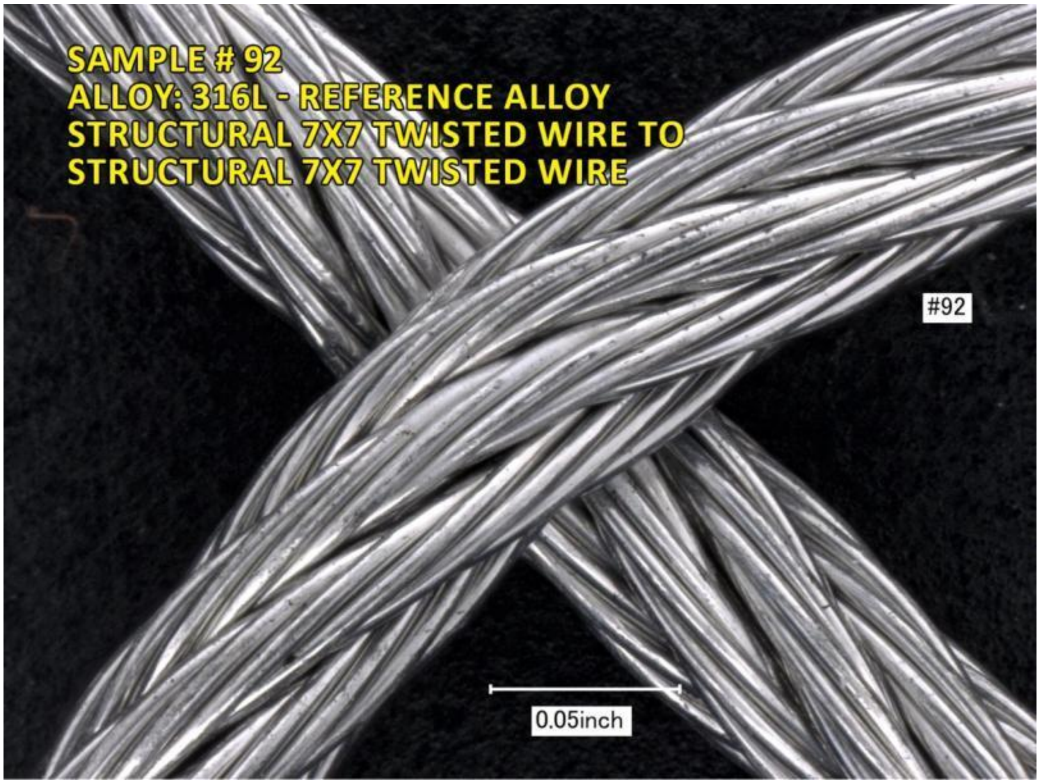
(~40X)


SAMPLE # 91
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#91
0.05inch

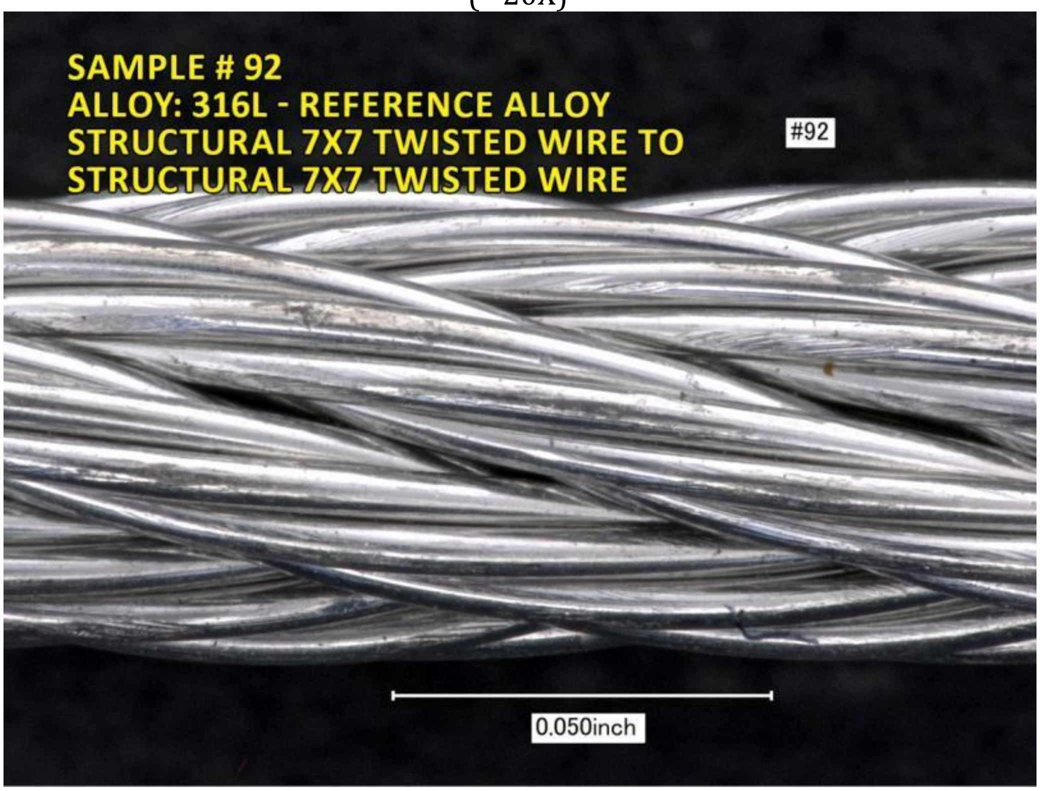
(~20X)


SAMPLE # 91
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#91
0.050inch

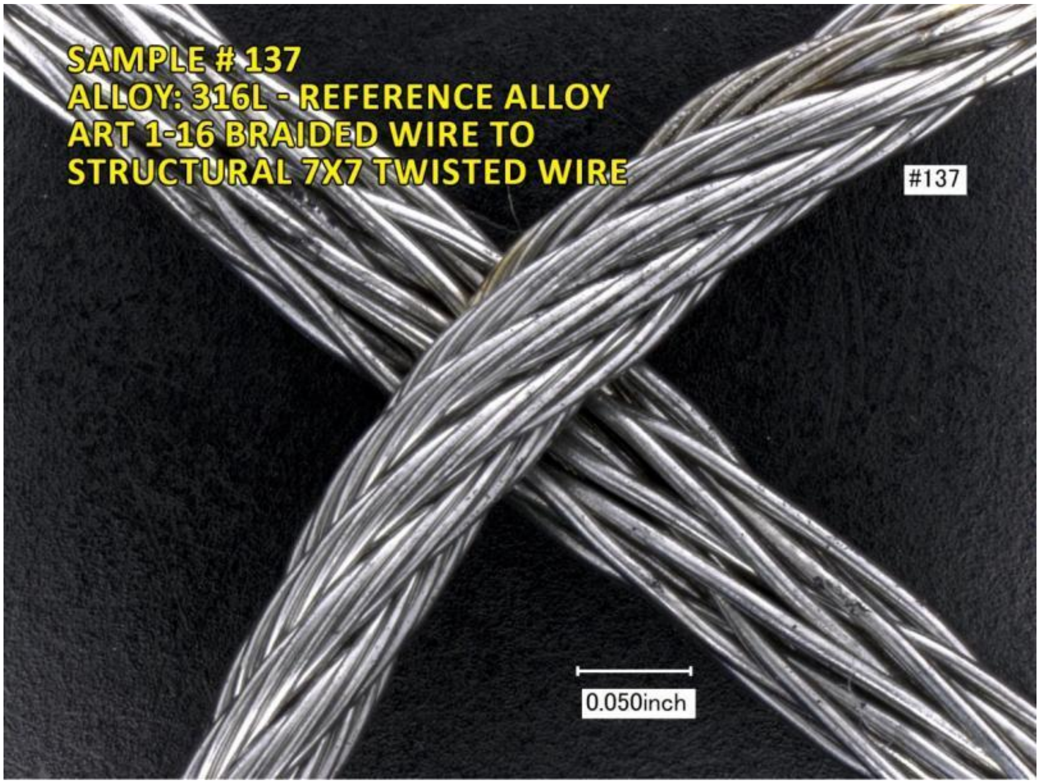
(~40X)


SAMPLE # 92
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#92
0.05inch

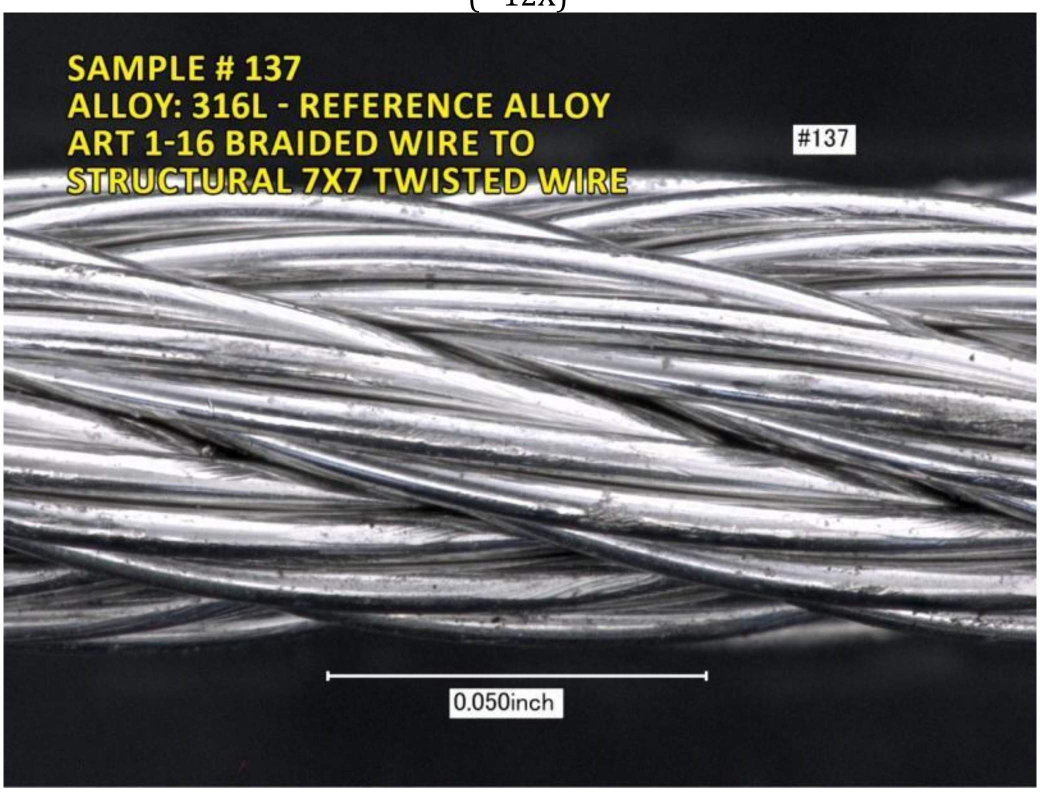
(~20X)


SAMPLE # 92
ALLOY: 316L - REFERENCE ALLOY
STRUCTURAL 7X7 TWISTED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#92
0.050inch

(~40X)


SAMPLE # 137
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#137
0.050inch

(~12X)


SAMPLE # 137
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#137
0.050inch

(~40X)


SAMPLE # 137
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#137
0.050inch

(~40X)


SAMPLE # 138
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#138
0.05inch

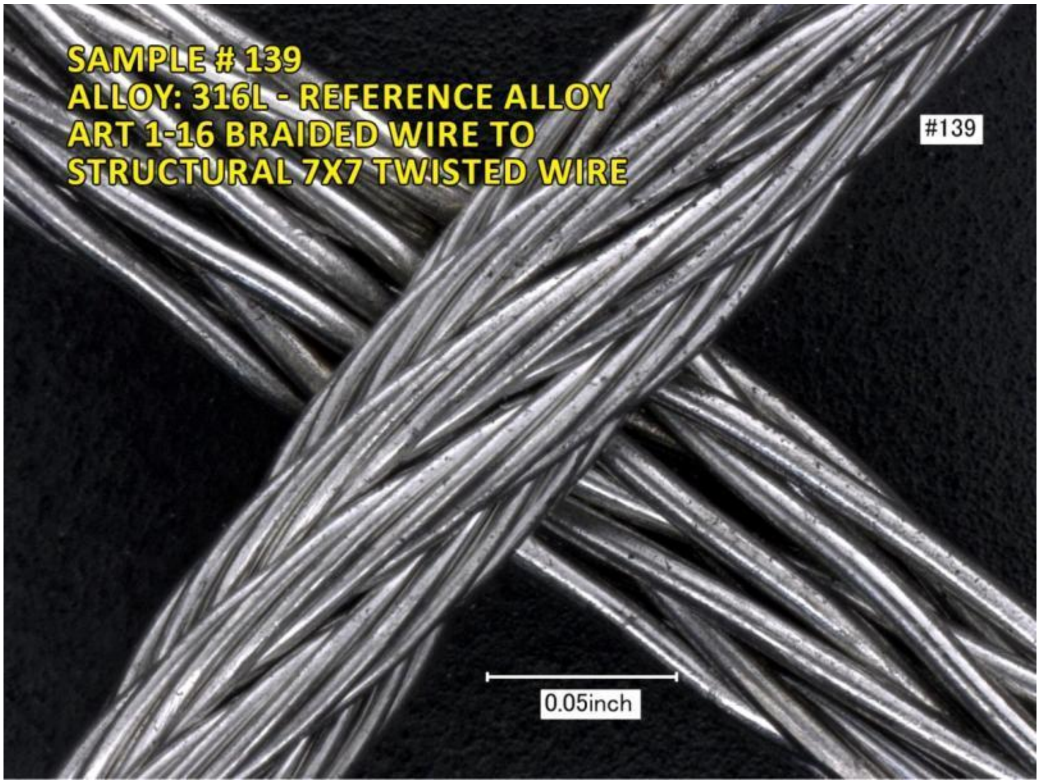
(~20X)


SAMPLE # 138
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#138
0.050inch

(~40X)


SAMPLE # 138
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#138
0.050inch

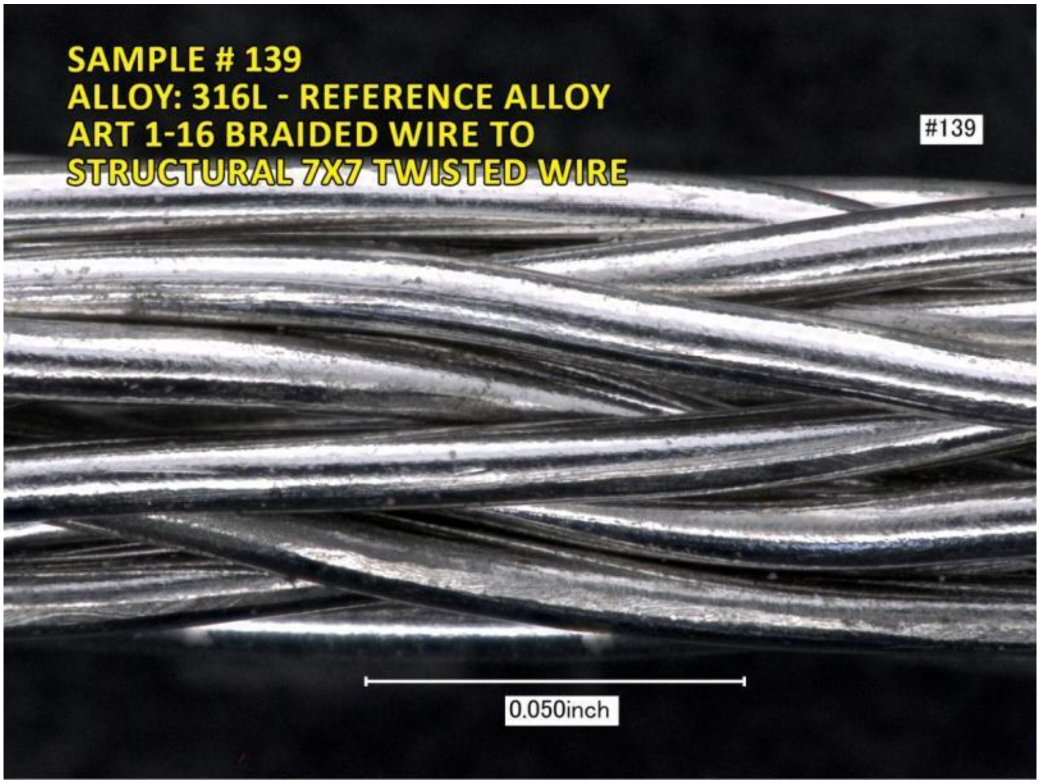
(~40X)


SAMPLE # 139
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#139
0.05inch

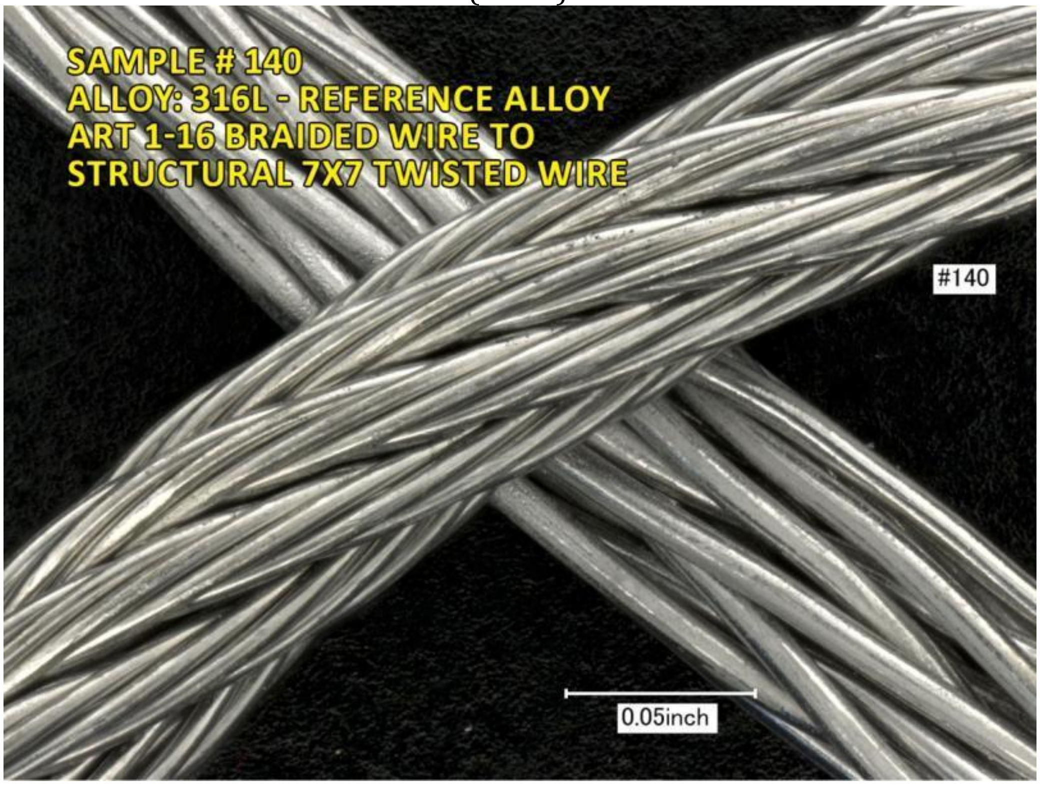
(~20X)


SAMPLE # 139
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#139
0.050inch

(~40X)


SAMPLE # 139
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#139
0.050inch

(~40X)


SAMPLE # 140
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#140
0.05inch

(~20X)


SAMPLE # 140
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#140
0.050inch

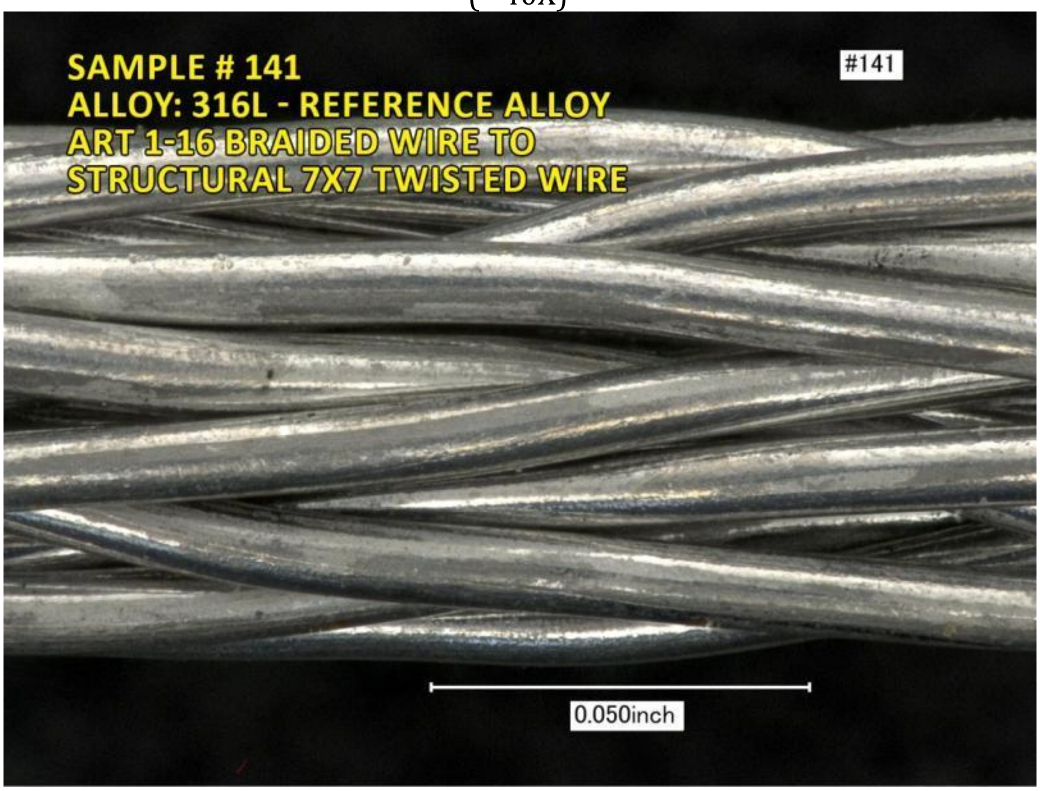
(~40X)


SAMPLE # 140
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#140
0.050inch

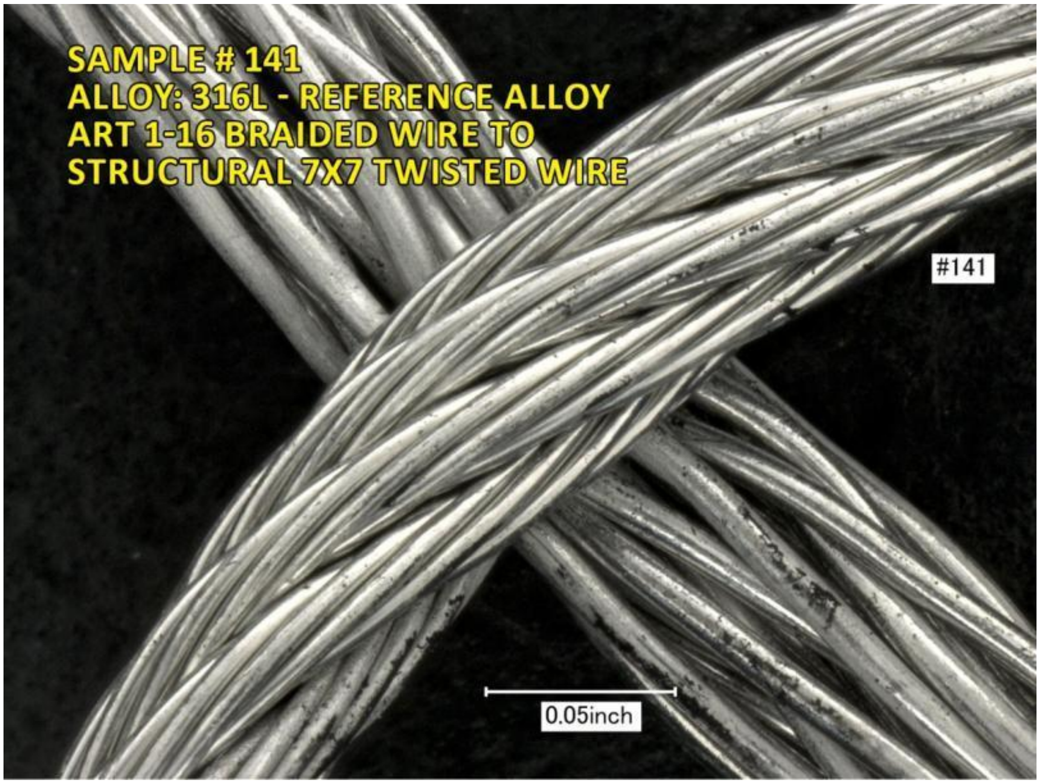
(~40X)


SAMPLE # 141
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#141
0.050inch

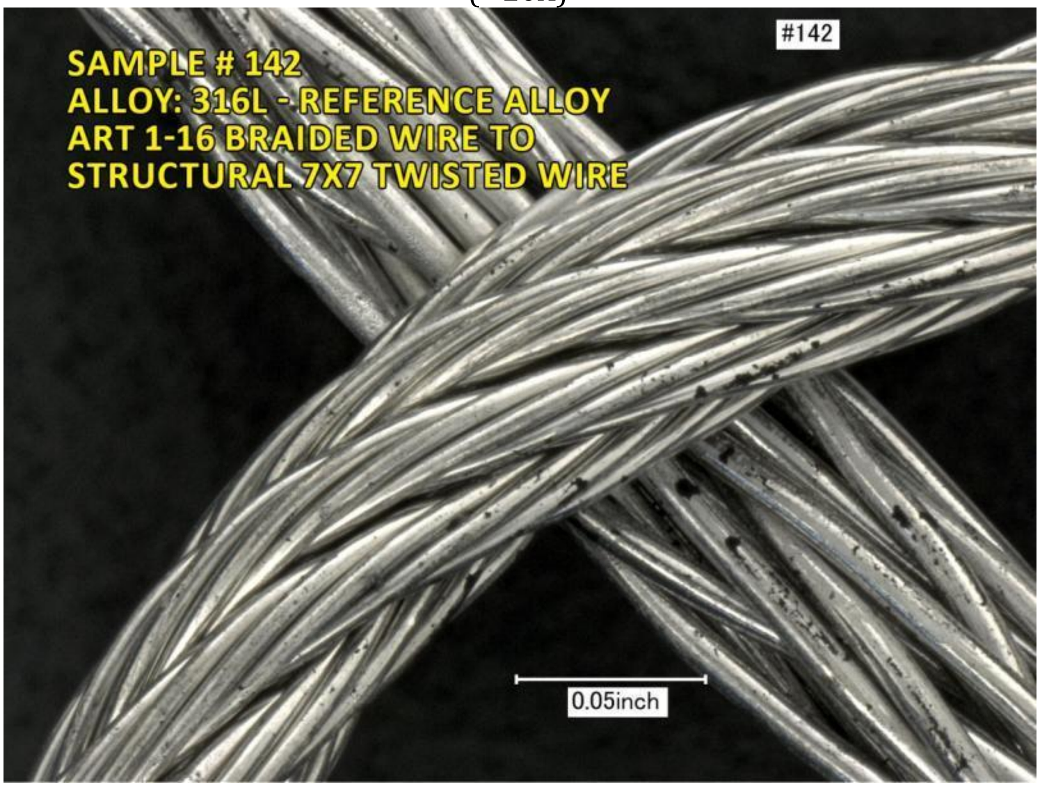
(~40X)


SAMPLE # 141
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#141
0.050inch

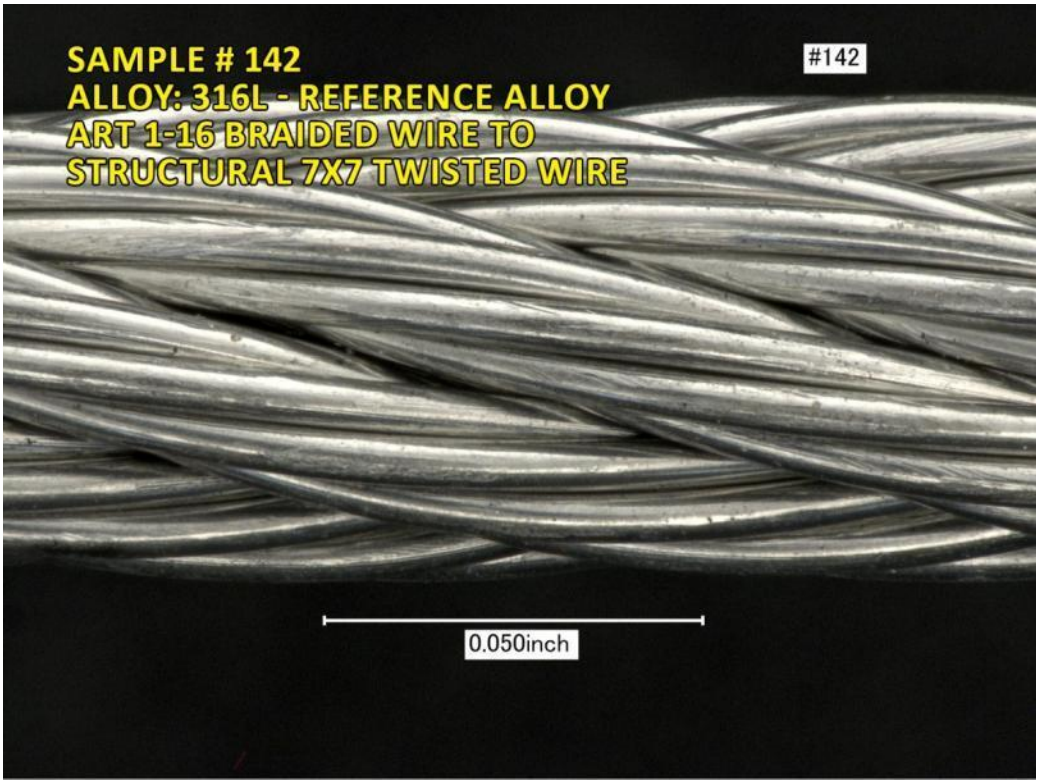
(~40X)


SAMPLE # 141
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#141
0.05inch

(~20X)


#142
SAMPLE # 142
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
0.05inch

(~20X)


SAMPLE # 142
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#142
0.050inch

(~40X)


SAMPLE # 142
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
STRUCTURAL 7X7 TWISTED WIRE
#142
0.050inch

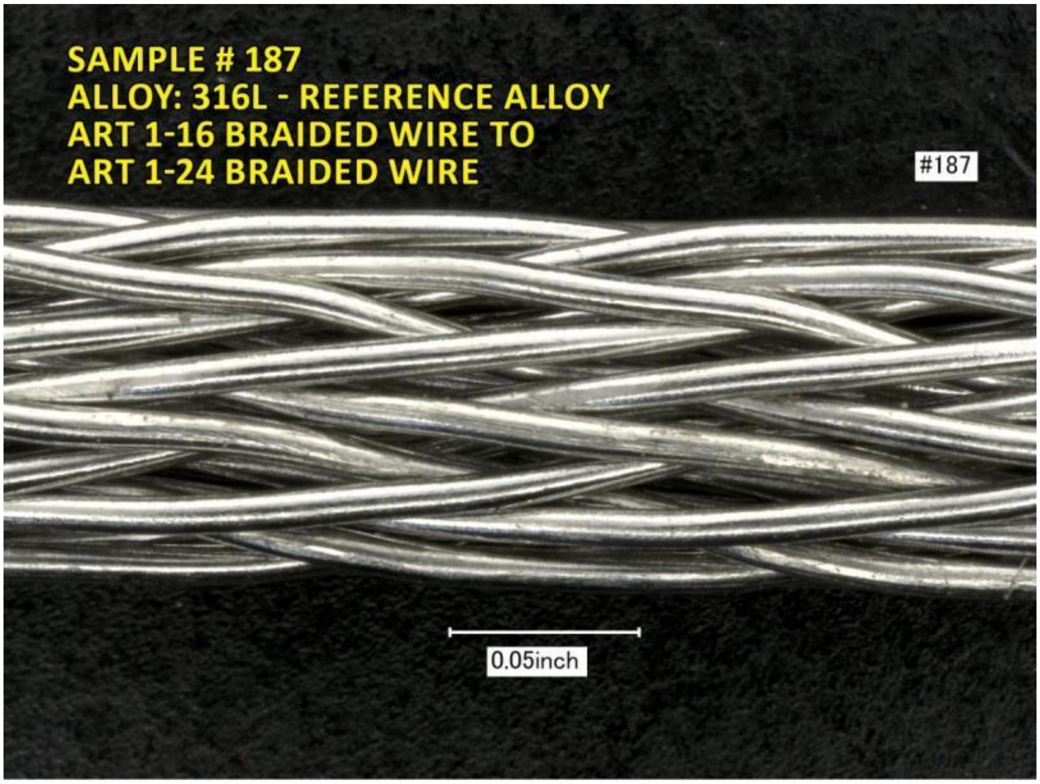
(~40X)


SAMPLE # 187
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#187
0.050inch

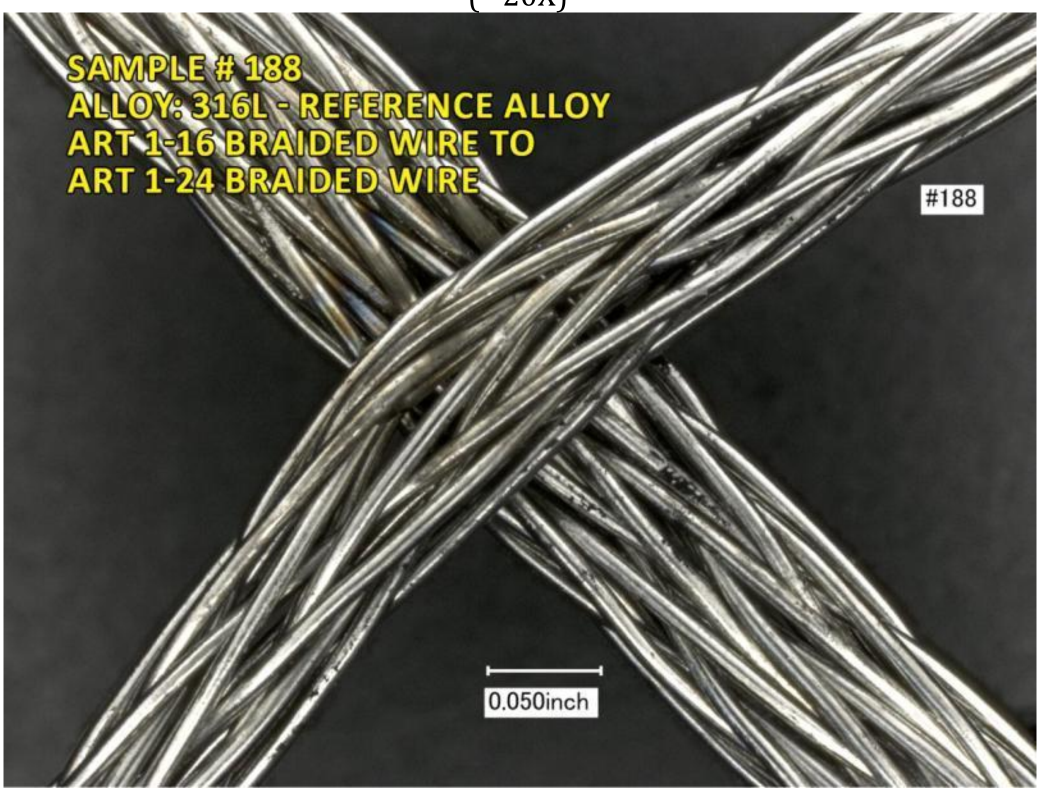
(~12X)


SAMPLE # 187
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#187
0.050inch

(~40X)


SAMPLE # 187
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#187
0.05inch

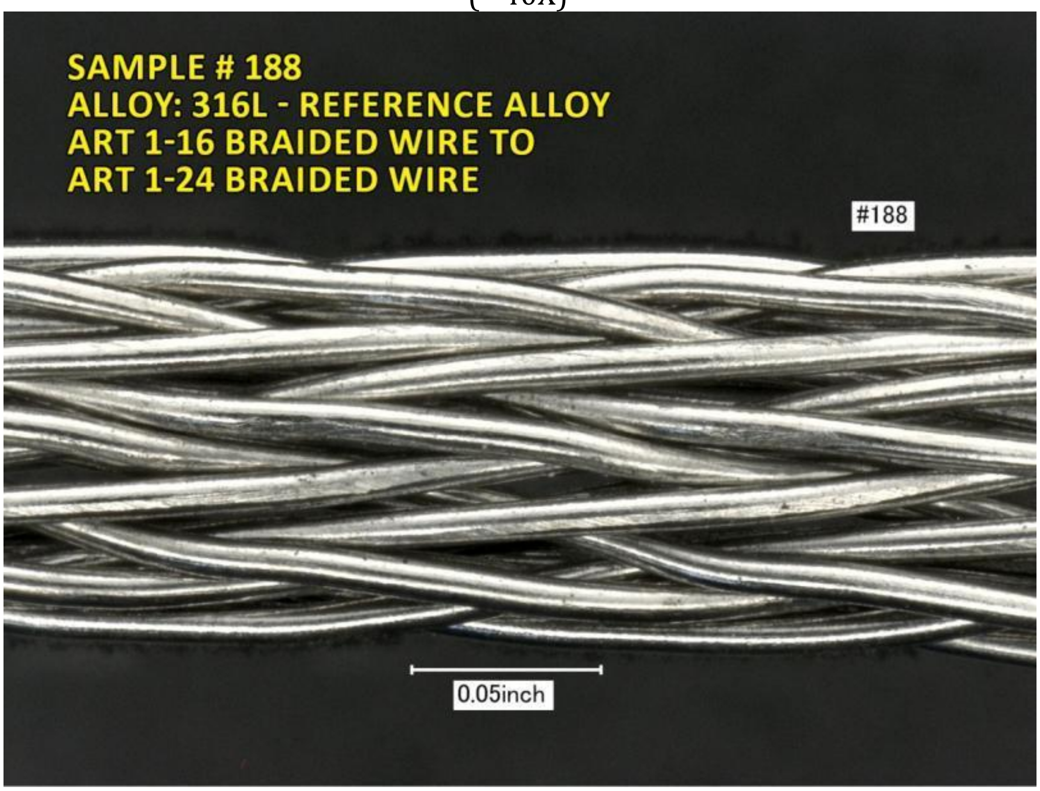
(~20X)


SAMPLE # 188
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#188
0.050inch

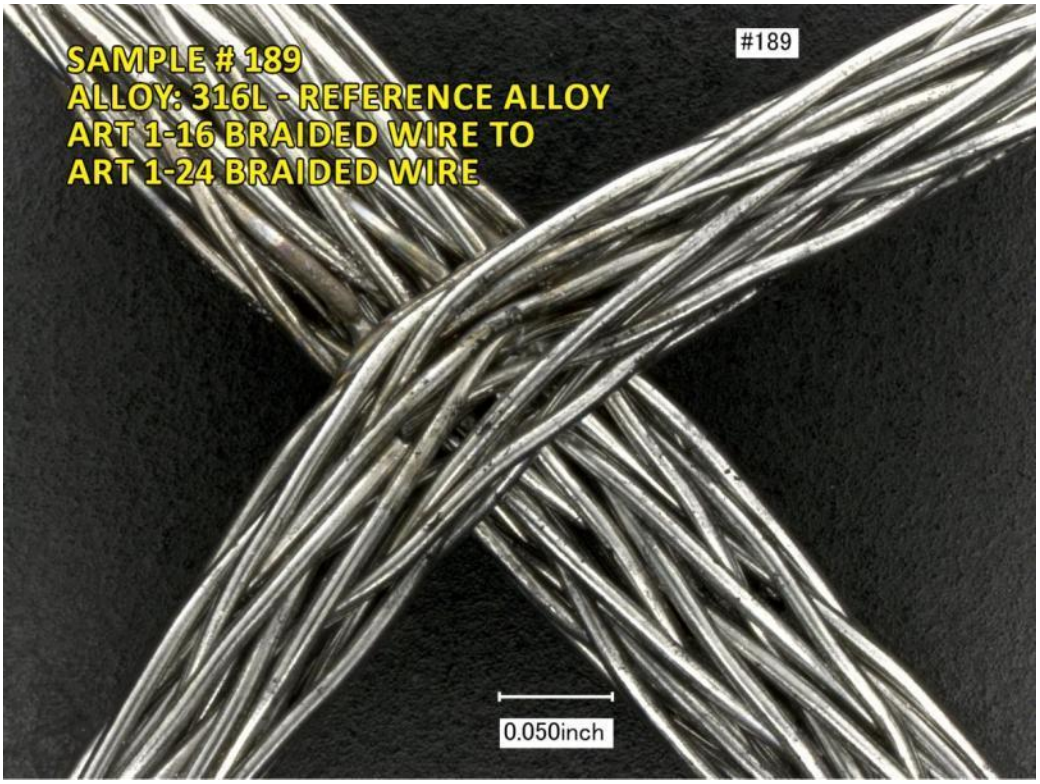
(~12X)


SAMPLE # 188
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#188
0.050inch

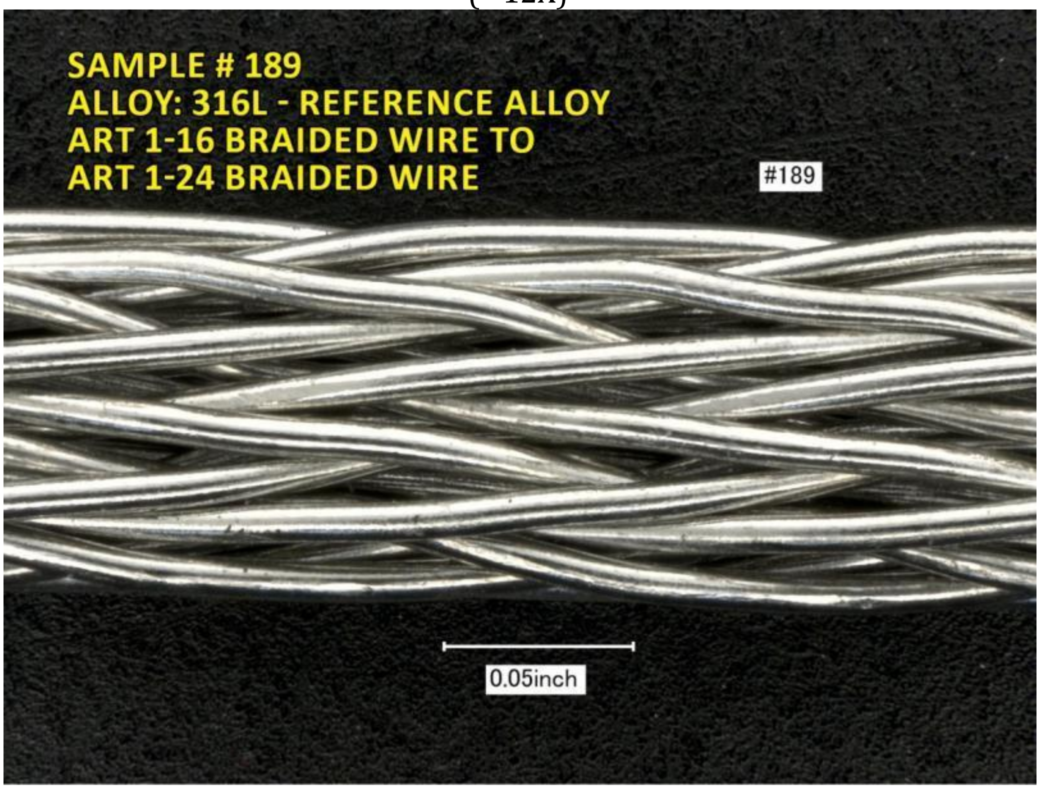
(~40X)


SAMPLE # 188
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#188
0.05inch

(~20X)


SAMPLE # 189
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#189
0.050inch

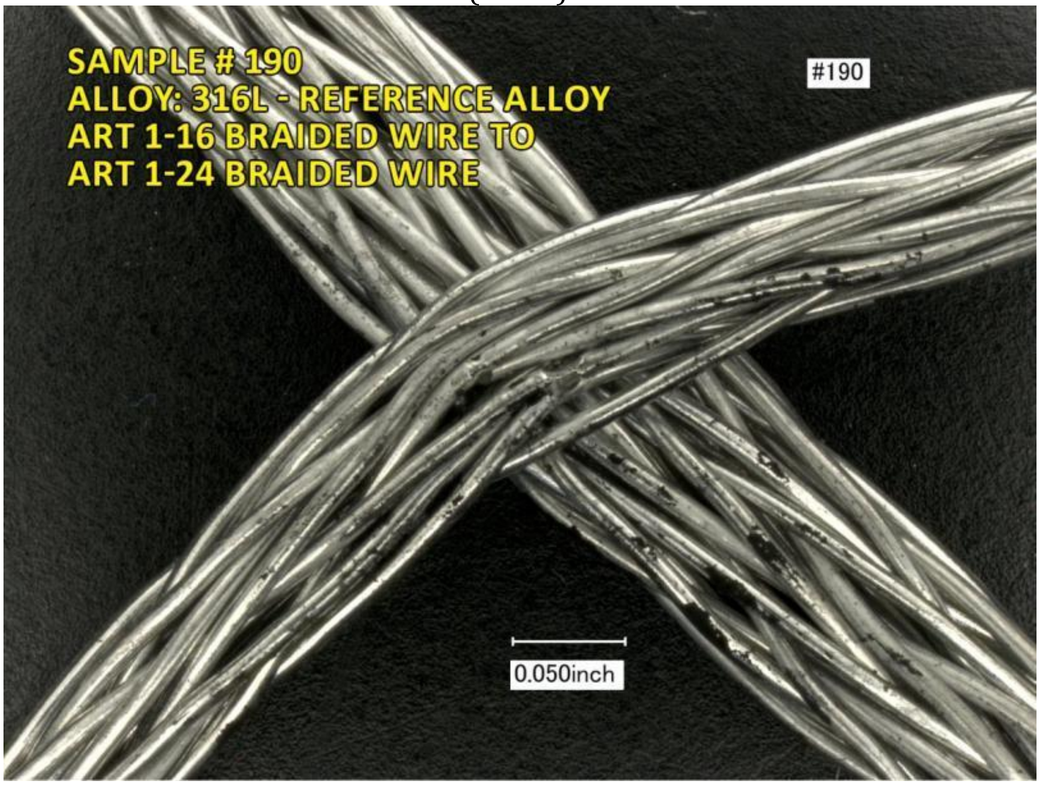
(~12X)


SAMPLE # 189
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#189
0.05inch

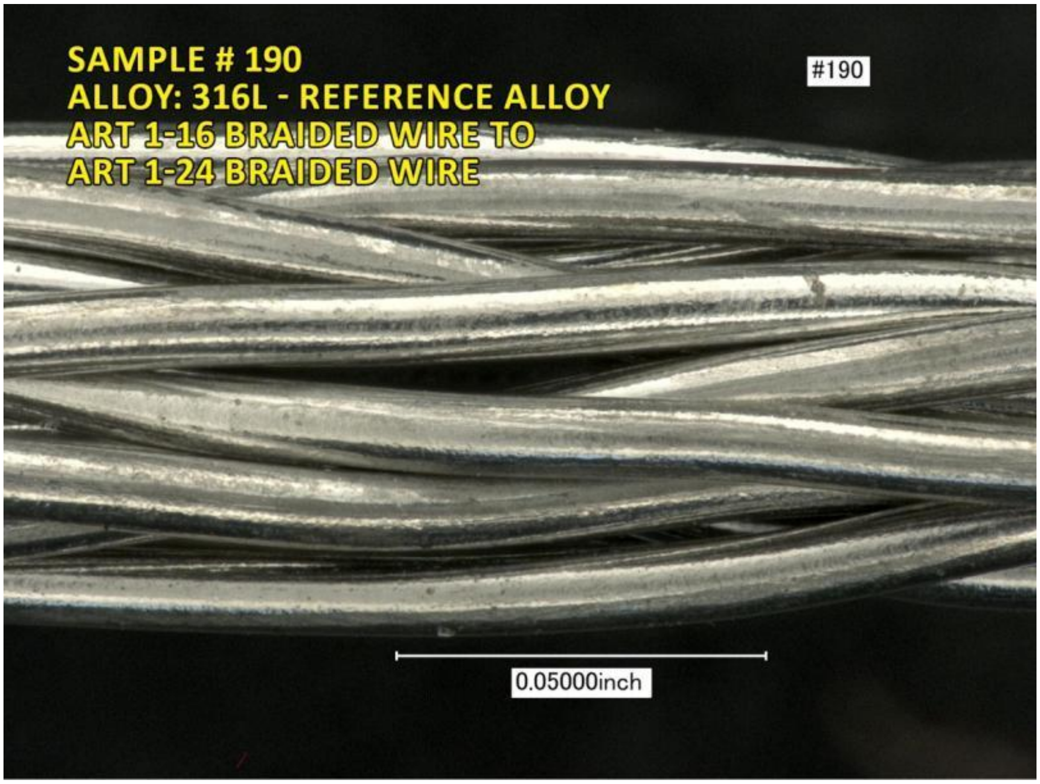
(~20X)


SAMPLE # 189
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#189
0.050inch

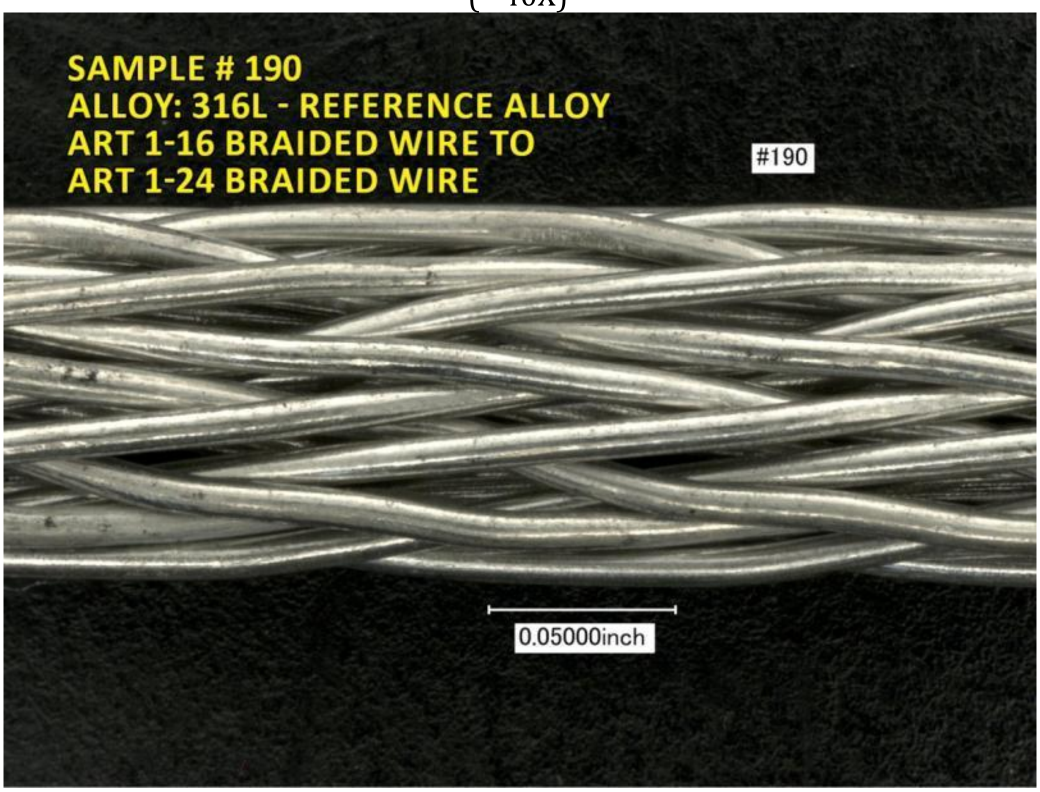
(~40X)


SAMPLE # 190
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#190
0.050inch

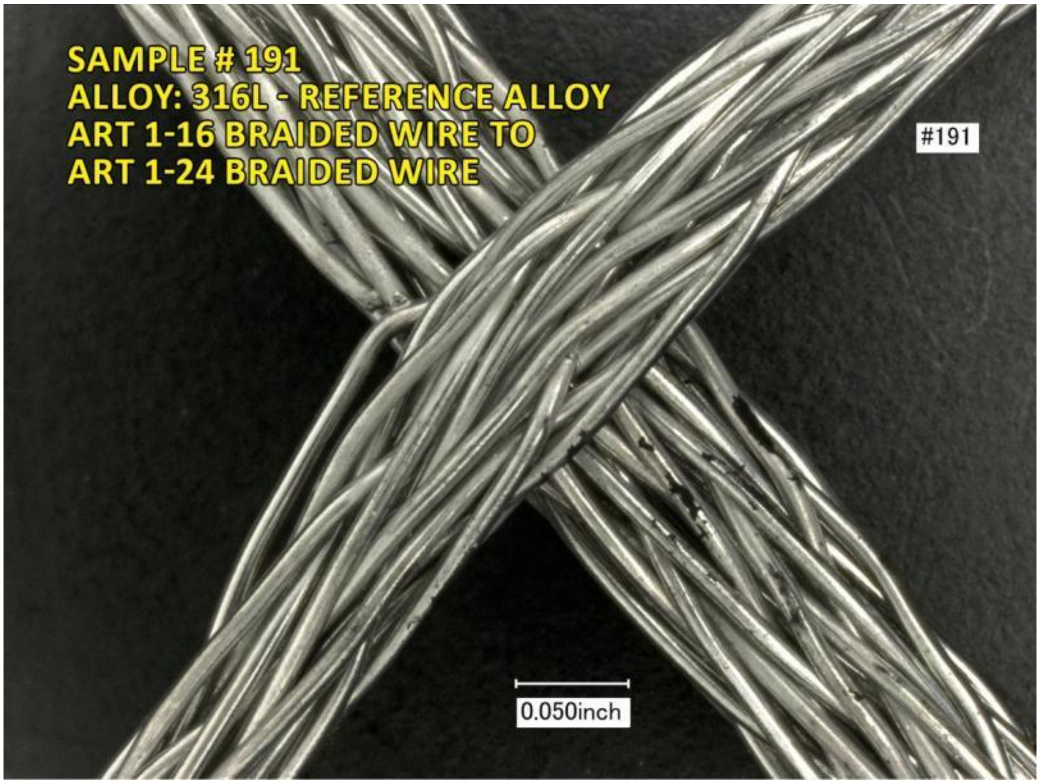
(~12X)


SAMPLE # 190
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#190
0.05000inch

(~40X)


SAMPLE # 190
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#190
0.05000inch

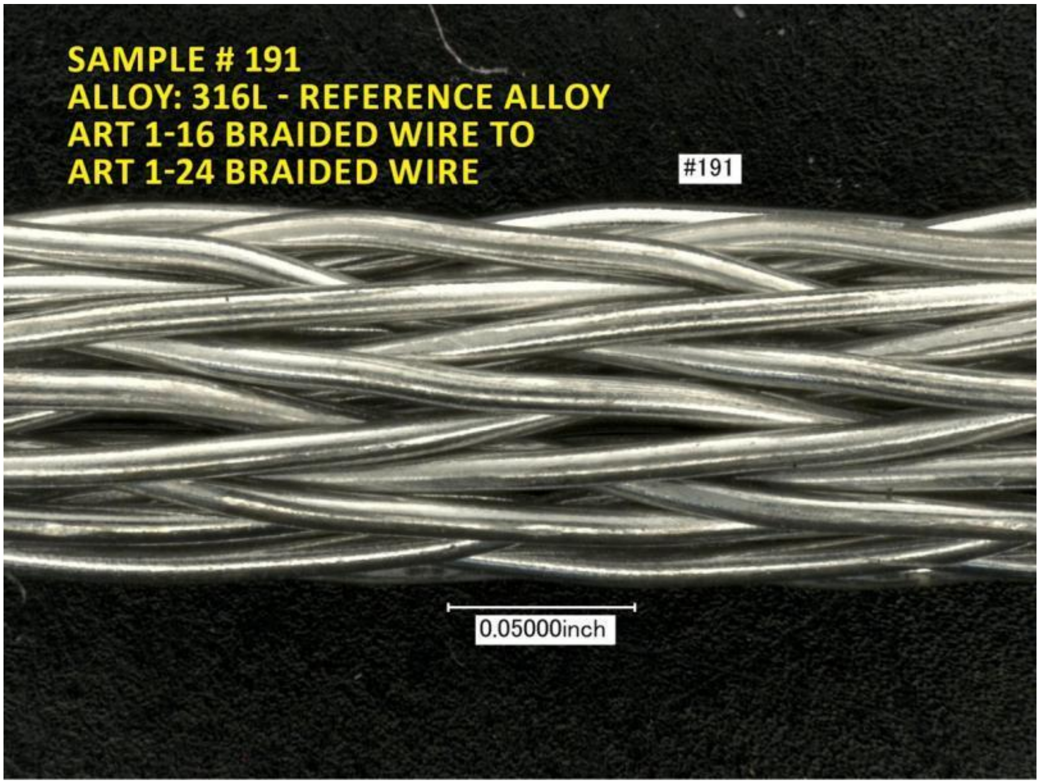
(~20X)


SAMPLE # 191
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#191
0.050inch

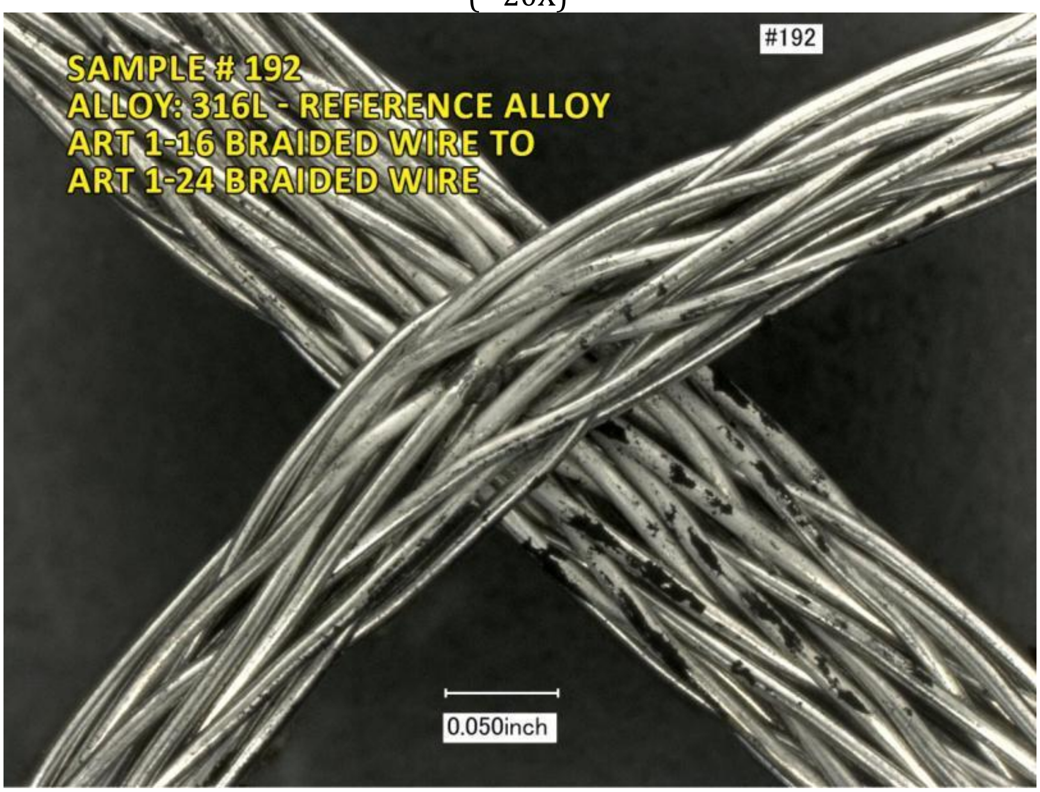
(~12X)


SAMPLE # 191
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#191
0.05000inch

(~40X)


SAMPLE # 191
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#191
0.05000inch

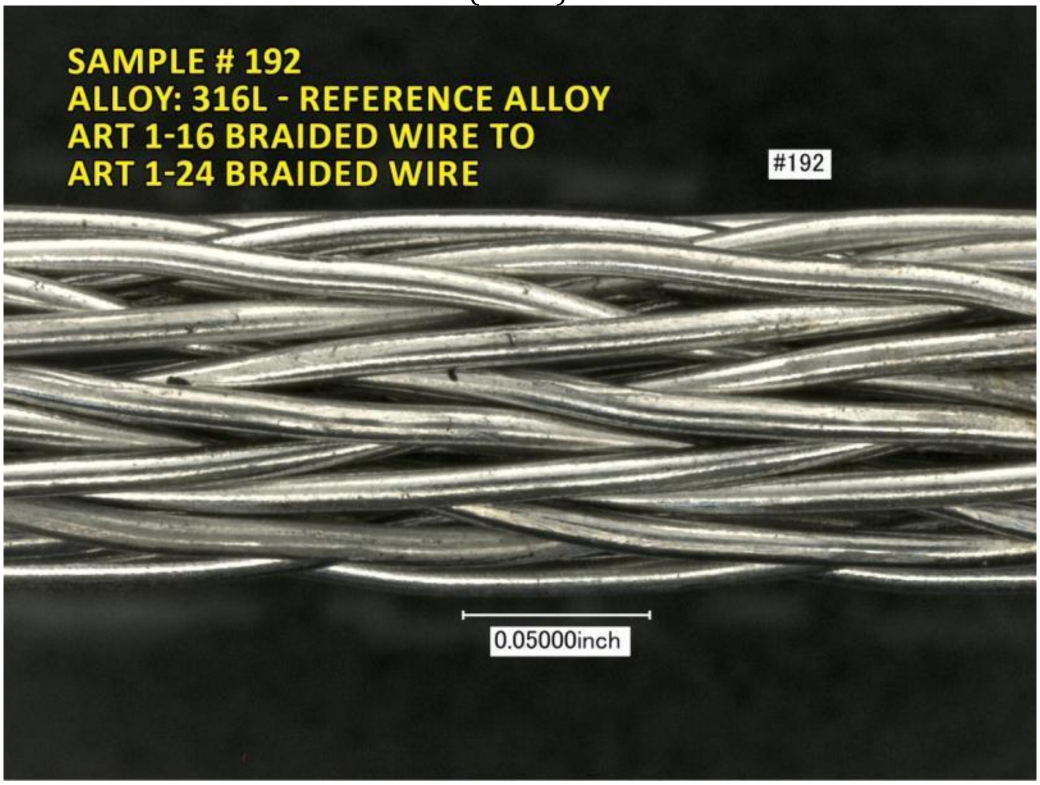
(~20X)


#192
SAMPLE # 192
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
0.050inch

(~20X)


SAMPLE # 192
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#192
0.05000inch

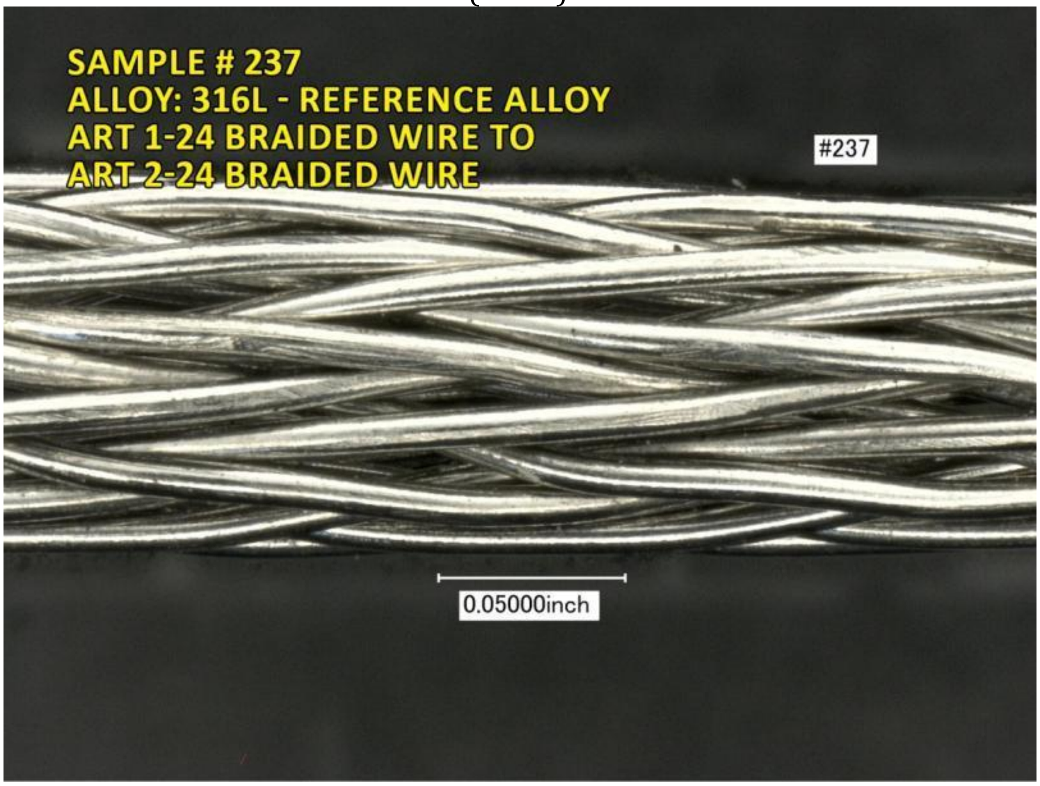
(~40X)


SAMPLE # 192
ALLOY: 316L - REFERENCE ALLOY
ART 1-16 BRAIDED WIRE TO
ART 1-24 BRAIDED WIRE
#192
0.05000inch

(~20X)


SAMPLE # 237
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#237
0.050inch

(~12X)


SAMPLE # 237
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#237
0.05000inch

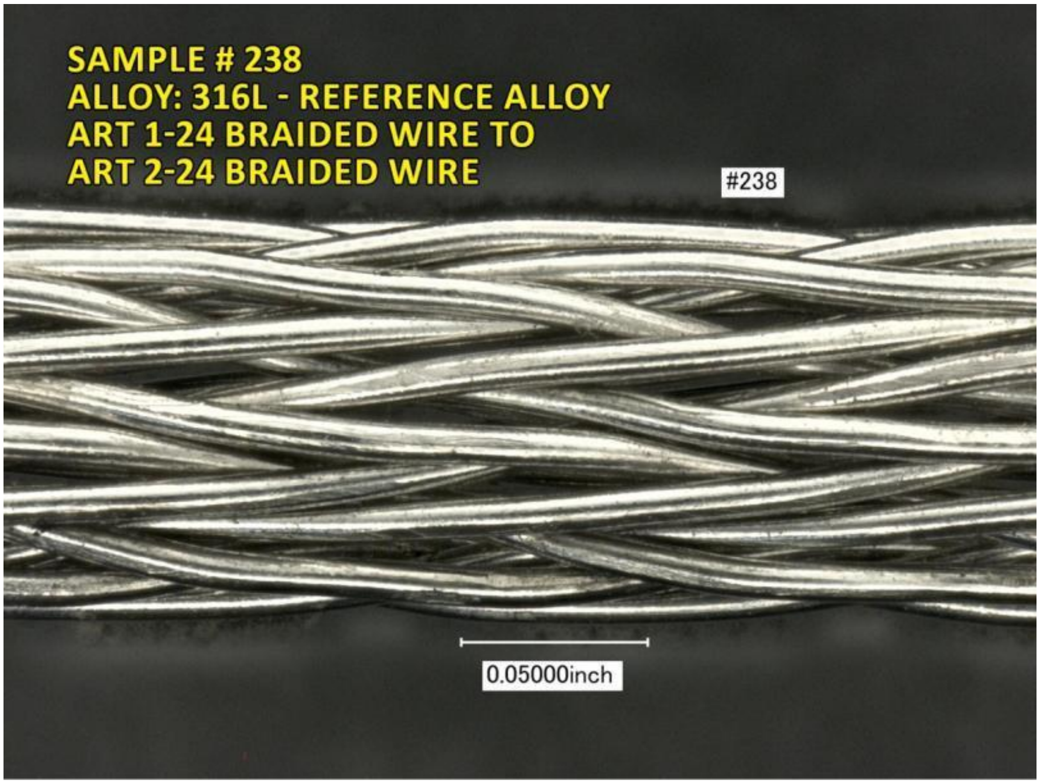
(~20X)


#237
SAMPLE # 237
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
0.05000inch

(~20X)


#238
SAMPLE # 238
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
0.050inch

(~12X)


SAMPLE # 238
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#238
0.05000inch

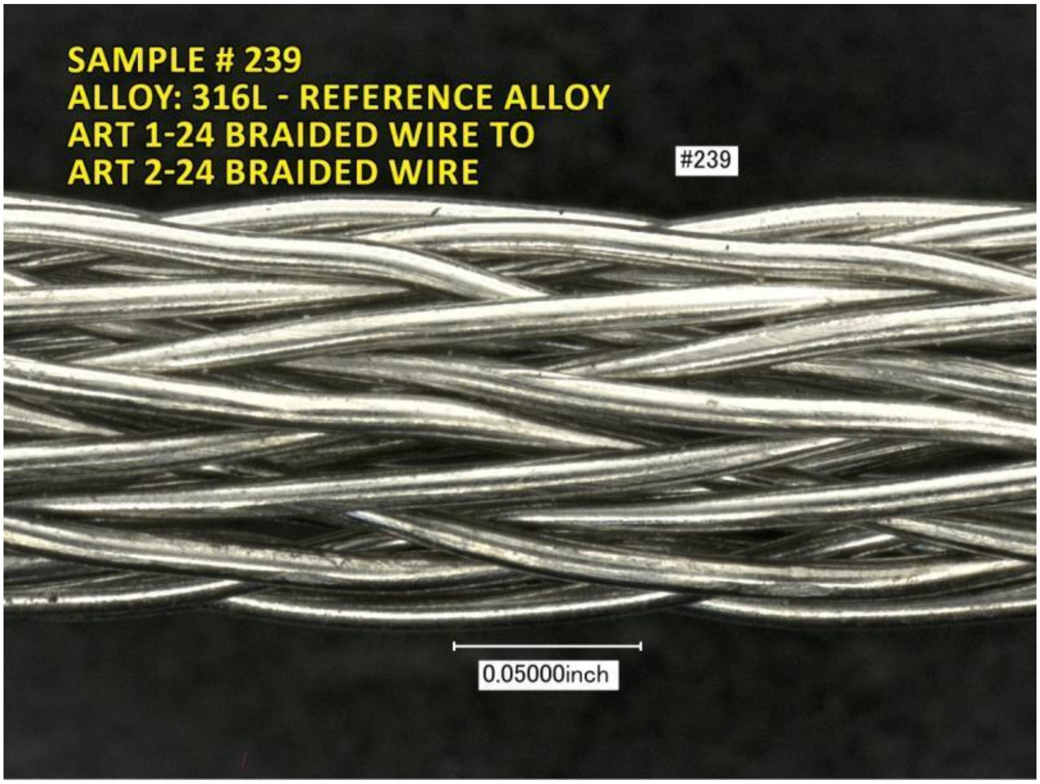
(~20X)


SAMPLE # 238
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#238
0.05000inch

(~20X)


SAMPLE # 239
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#239
0.050inch

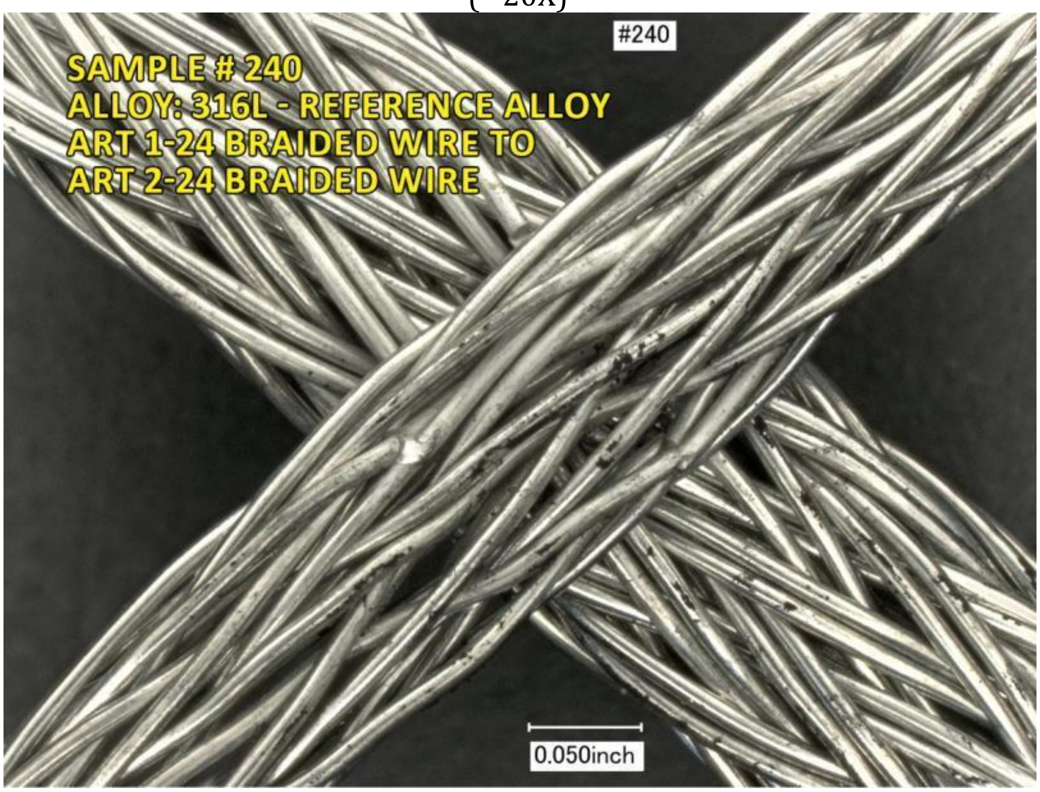
(~12X)


SAMPLE # 239
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#239
0.05000inch

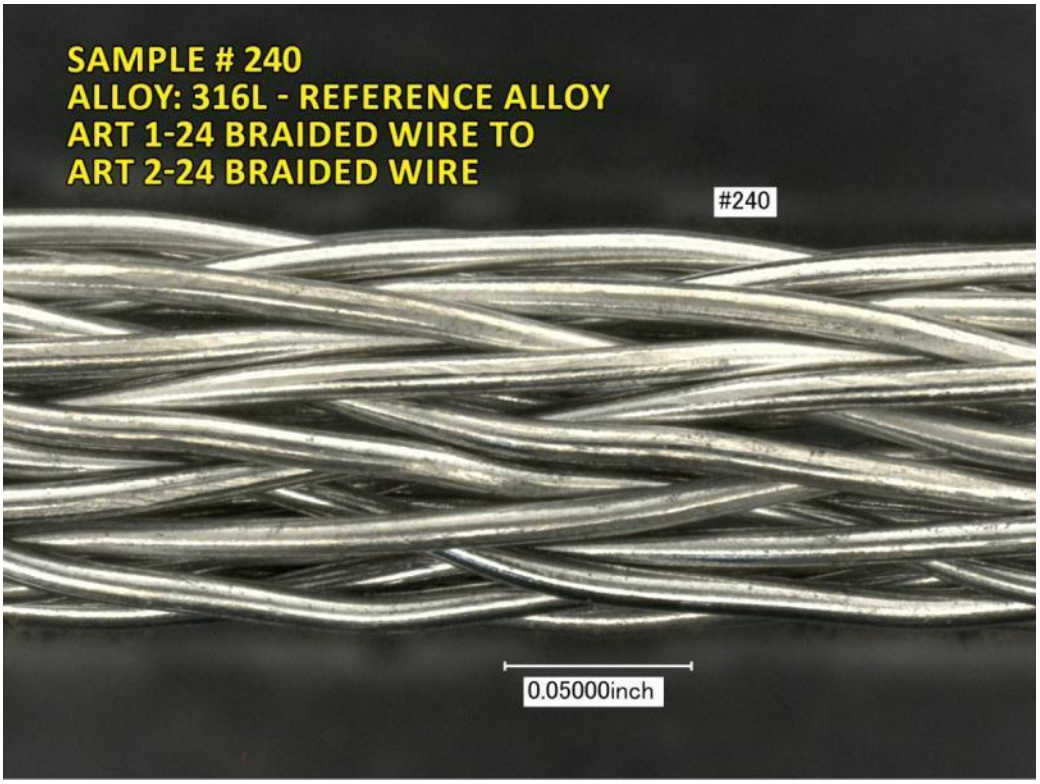
(~20X)


SAMPLE # 239
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#239
0.05000inch

(~20X)


SAMPLE # 240
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#240
0.050inch

(~12X)


SAMPLE # 240
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#240
0.05000inch

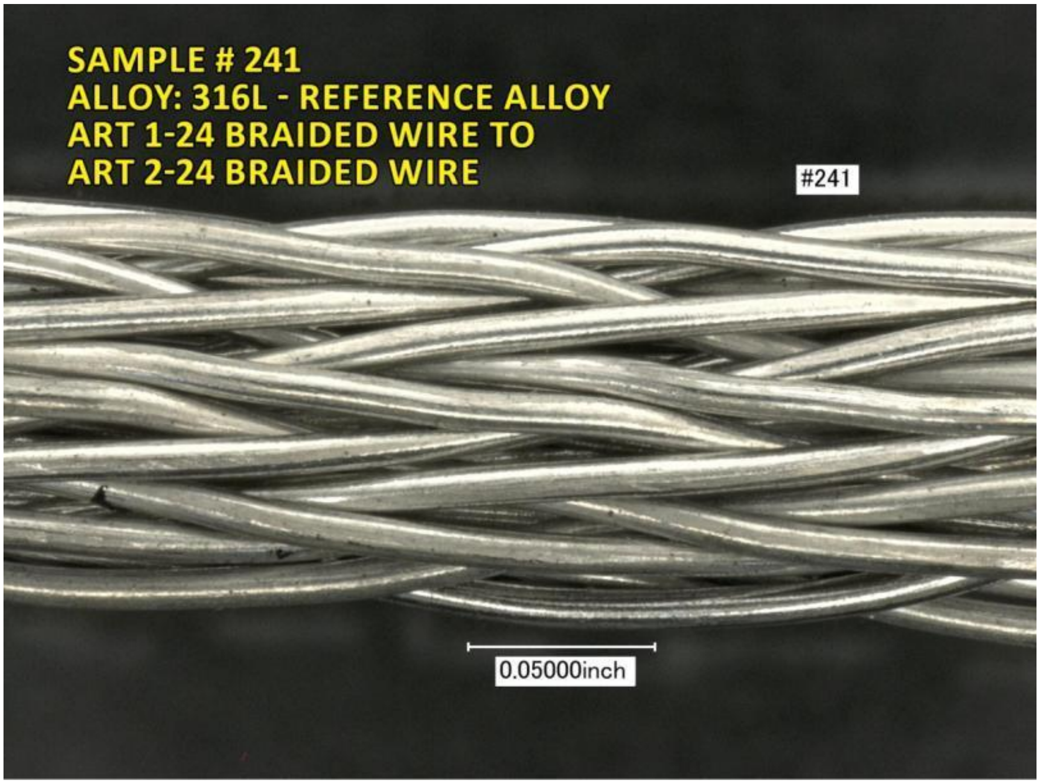
(~20X)


#240
SAMPLE # 240
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
0.05000inch

(~20X)


SAMPLE # 241
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#241
0.050inch

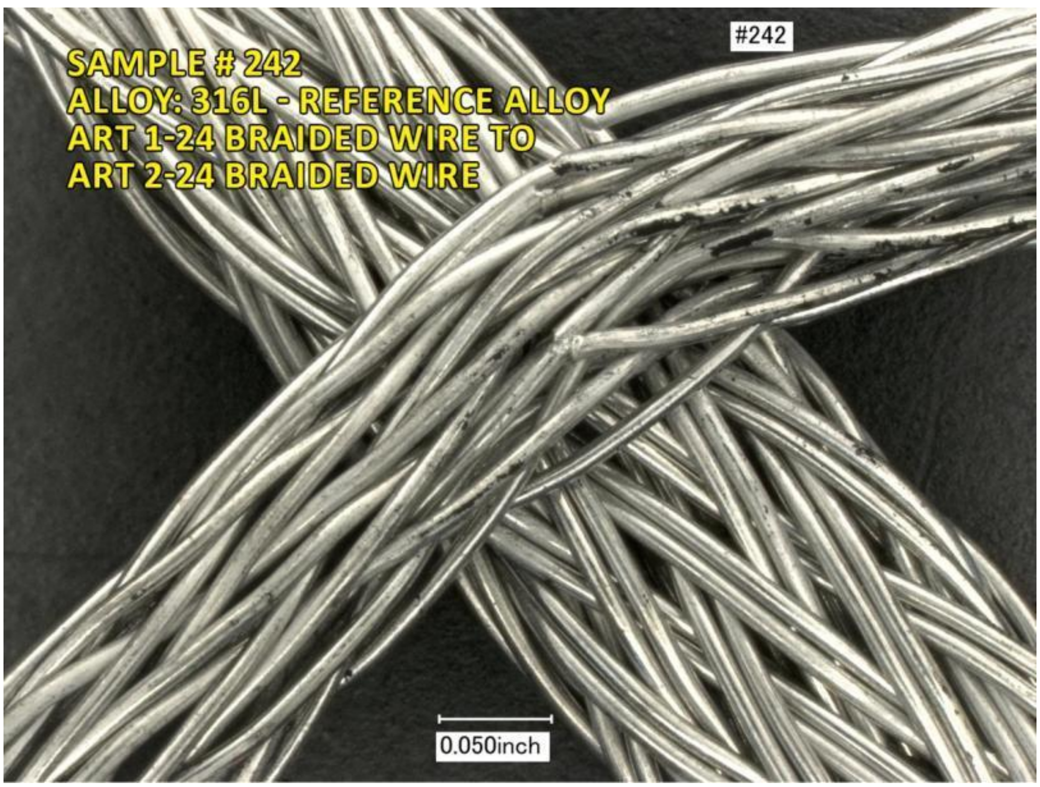
(~12X)


SAMPLE # 241
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#241
0.05000inch

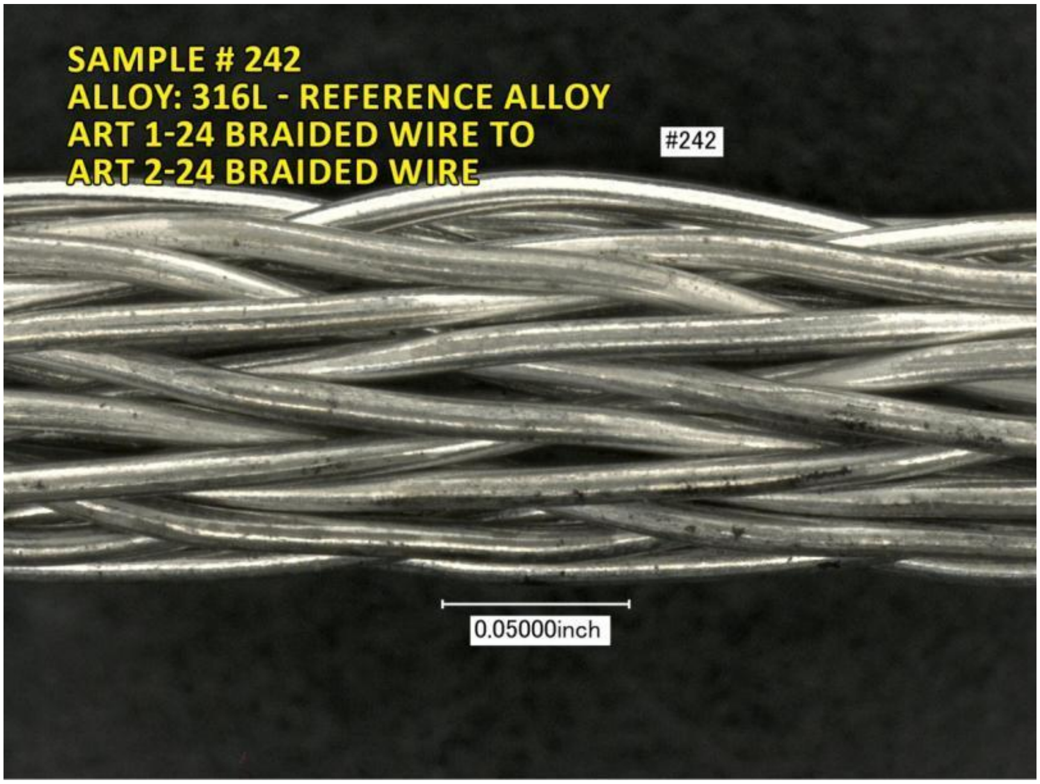
(~20X)


#241
SAMPLE # 241
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
0.05000inch

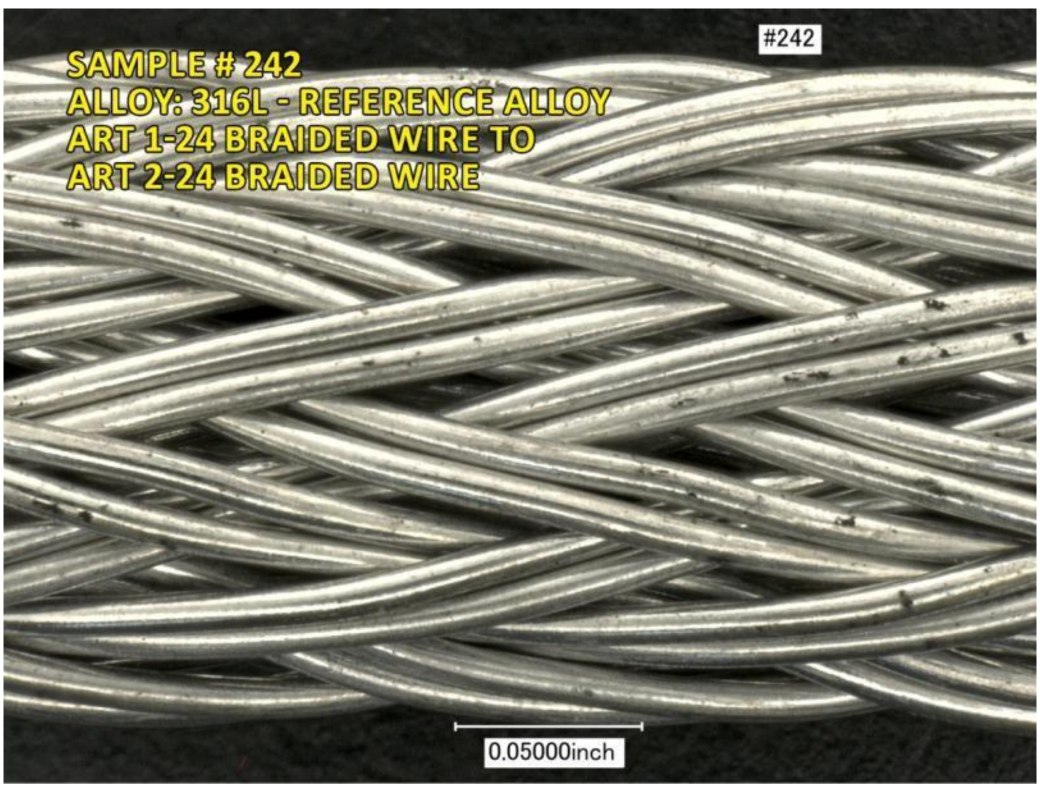
(~20X)


#242
SAMPLE # 242
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
0.050inch

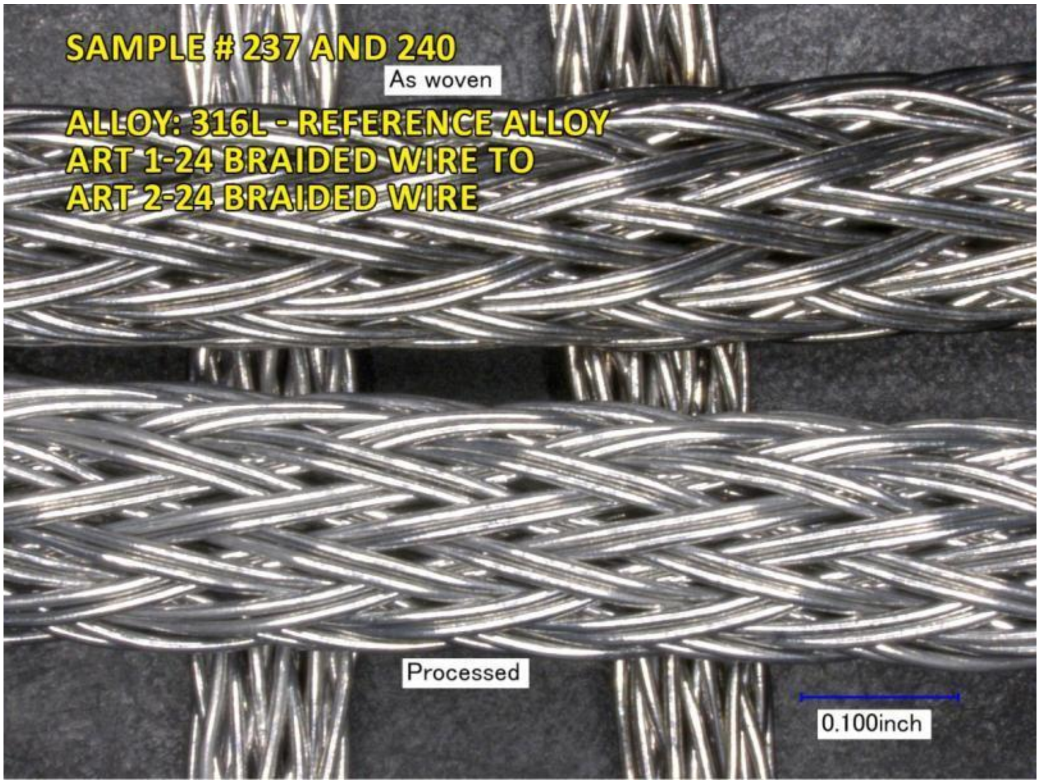
(~12X)


SAMPLE # 242
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
#242
0.05000inch

(~20X)


#242
SAMPLE # 242
ALLOY: 316L - REFERENCE ALLOY
ART 1-24 BRAIDED WIRE TO
ART 2-24 BRAIDED WIRE
0.05000inch

(~20X)



(~8X)

Digital stereo micrograph showing Sample # 237 and Sample #240 after salt spray testing at Anachem Laboratories for 1000 hours. Sample # 240 had been descaled and passivated prior to salt spray testing while Sample #237 was salt spray tested in the as-welded condition.

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ANACHEM LABORATORIES

Established 1948

140 Standard Street · El Segundo, California 90245.3832 · voice 310.322.4993 · fax 310.322.6681

TEST REPORT

TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE	December 3, 2013
LAB NO.	B78714 pg.1 of 10
CUST P.O.	
SAMPLE NO.	67009
RECEIVED	10/9/13

SAMPLE: 21 pcs Welded Cross (Set 1B)
317L Structural 7x7 Twisted Wire to 317L Structural 7x7 Twisted Wire

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received

CONDITION: None - test as received

TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2

POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry

EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
19	No visible change
20	No visible change
21	No visible change
22	No visible change
23	No visible change
24	No visible change
25	No visible change
26	No visible change
27	No visible change
28	No visible change
29	No visible change
30	No visible change
31	No visible change
32	No visible change
33	No visible change
34	No visible change
35	No visible change
36	No visible change
37	No visible change
38	No visible change
39	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

Accredited Nadcap Chemical Processing

TEST REPORT

ANACHEM LABORATORIES

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TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE	December 3, 2013
LAB NO.	B78714 pg.2 of 10
CUST P.O.	
SAMPLE NO.	67202
RECEIVED	10/16/13

SAMPLE: 3 pcs Welded Cross (Set 1B)
317L Structural 7x7 Twisted Wire to 317L Structural 7x7 Twisted Wire
Descaled and Passivated

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN:	None - test as received
CONDITION:	None - test as received
TESTING:	Coat samples with Lamp Black Rack samples and apply approximate 2-lb weight 1000 hours @ 95±3°F Constant spray of 5±1 %/wt Sodium Chloride Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN:	Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION:	Final evaluation by customer

SAMPLE	**OBSERVATION**
40	No visible change
41	No visible change
42	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

Accredited Nadcap Chemical Processing

TEST REPORT

ANACHEM LABORATORIES

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TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE	December 3, 2013
LAB NO.	B78714 pg.3 of 10
CUST P.O.	
SAMPLE NO.	67009
RECEIVED	10/9/13

SAMPLE: 21 pcs Welded Cross (Set 2B)
316L Structural 7x7 Twisted Wire to 316L Structural 7x7 Twisted Wire

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received
CONDITION: None - test as received
TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
69	No visible change
70	No visible change
71	No visible change
72	No visible change
73	No visible change
74	No visible change
75	No visible change
76	No visible change
77	No visible change
78	No visible change
79	No visible change
80	No visible change
81	No visible change
82	No visible change
83	No visible change
84	No visible change
85	No visible change
86	No visible change
87	No visible change
88	No visible change
89	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

Accredited Nadcap Chemical Processing

ANACHEM LABORATORIES

TEST REPORT

Established 1948

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TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE	December 3, 2013
LAB NO.	B78714 pg.4 of 10
CUST P.O.	
SAMPLE NO.	67202
RECEIVED	10/16/13

SAMPLE: 3 pcs Welded Cross (Set 2B)
316L Structural 7x7 Twisted Wire to 316L Structural 7x7 Twisted Wire
Descaled and Passivated

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN:	None - test as received
CONDITION:	None - test as received
TESTING:	Coat samples with Lamp Black Rack samples and apply approximate 2-lb weight 1000 hours @ 95±3°F Constant spray of 5±1 %/wt Sodium Chloride Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN:	Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION:	Final evaluation by customer

SAMPLE	**OBSERVATION**
90	No visible change
91	No visible change
92	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

TEST REPORT

ANACHEM LABORATORIES

Established 1948

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TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE	December 3, 2013
LAB NO.	B78714 pg.5 of 10
CUST P.O.	
SAMPLE NO.	67009
RECEIVED	10/9/13

SAMPLE: 21 pcs Welded Cross (Set 3B)
316L Art 1-16 Braided Wire to 316L Structural 7x7 Twisted Wire

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received
CONDITION: None - test as received
TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
119	No visible change
120	No visible change
121	No visible change
122	No visible change
123	No visible change
124	No visible change
125	No visible change
126	No visible change
127	No visible change
128	No visible change
129	No visible change
130	No visible change
131	No visible change
132	No visible change
133	No visible change
134	No visible change
135	No visible change
136	No visible change
137	No visible change
138	No visible change
139	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

Accredited Nadcap Chemical Processing

ANACHEM LABORATORIES

TEST REPORT

Established 1948

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TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE December 3, 2013
LAB NO. B78714 pg.6 of 10
CUST P.O.
SAMPLE NO. 67202
RECEIVED 10/16/13

SAMPLE: 3 pcs Welded Cross (Set 3B)
316L Art 1-16 Braided Wire to 316L Structural 7x7 Twisted Wire
Descaled and Passivated

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received
CONDITION: None - test as received
TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
140	No visible change
141	No visible change
142	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

TEST REPORT

ANACHEM LABORATORIES

Established 1948

140 Standard Street • El Segundo, California 90245.3832 • voice 310.322.4993 • fax 310.322.6681

TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE December 3, 2013
LAB NO. B78714 pg.7 of 10
CUST P.O.
SAMPLE NO. 67009
RECEIVED 10/9/13

SAMPLE: 21 pcs Welded Cross (Set 4B)
316L Art 1-16 Braided Wire to 316L Art 1-24 Braided Wire

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received
CONDITION: None - test as received
TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
169	No visible change
170	No visible change
171	No visible change
172	No visible change
173	No visible change
174	No visible change
175	No visible change
176	No visible change
177	No visible change
178	No visible change
179	No visible change
180	No visible change
181	No visible change
182	No visible change
183	No visible change
184	No visible change
185	No visible change
186	No visible change
187	No visible change
188	No visible change
189	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

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TEST REPORT

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Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE December 3, 2013
LAB NO. B78714 pg.8 of 10
CUST P.O.
SAMPLE NO. 67202
RECEIVED 10/16/13

SAMPLE: 3 pcs Welded Cross (Set 4B)
316L Art 1-16 Braided Wire to 316L Art 1-24 Braided Wire
Descaled and Passivated

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received
CONDITION: None - test as received
TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
190	No visible change
191	No visible change
192	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

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General Manager

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TEST REPORT

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Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE December 3, 2013
LAB NO. B78714 pg.9 of 10
CUST P.O.
SAMPLE NO. 67009
RECEIVED 10/9/13

SAMPLE: 21 pcs Welded Cross (Set 5B)
316L Art 1-42 Braided Wire to 316L Art 2-24 Braided Wire

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received
CONDITION: None - test as received
TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
219	No visible change
220	No visible change
221	No visible change
222	No visible change
223	No visible change
224	No visible change
225	No visible change
226	No visible change
227	No visible change
228	No visible change
229	No visible change
230	No visible change
231	No visible change
232	No visible change
233	No visible change
234	No visible change
235	No visible change
236	No visible change
237	No visible change
238	No visible change
239	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

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TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE	December 3, 2013
LAB NO.	B78714 pg.10 of 10
CUST P.O.	
SAMPLE NO.	67202
RECEIVED	10/16/13

SAMPLE: 3 pcs Welded Cross (Set 5B)
316L Art 1-42 Braided Wire to 316L Art 2-24 Braided Wire
Descaled and Passivated

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received
CONDITION: None - test as received
TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
240	No visible change
241	No visible change
242	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

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4.4 MECHANICAL TENSION AND SHEAR STRENGTH ANALYSIS

Included in this section:

- Najjarine Structures Report Titled "Weld Capacity Report"
- Element Materials Technology Report # TOM002-21955M Titled *Mechanical Strength Testing of Welded Samples*

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STRUCTURAL ENGINEERS

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(949) 387-9440 T (949) 387-9207 F
www.najjarinestructures.com

WELD CAPACITY REPORT

Date: **02/03/2014**

Job Number: **12811**

Project: **Eisenhower Memorial**

Address: **Washington, DC**

Revisions:

Date:

Sheets:

The enclosed structural calculations are for the tapestry wall system and its anchorages related to the abovementioned project.

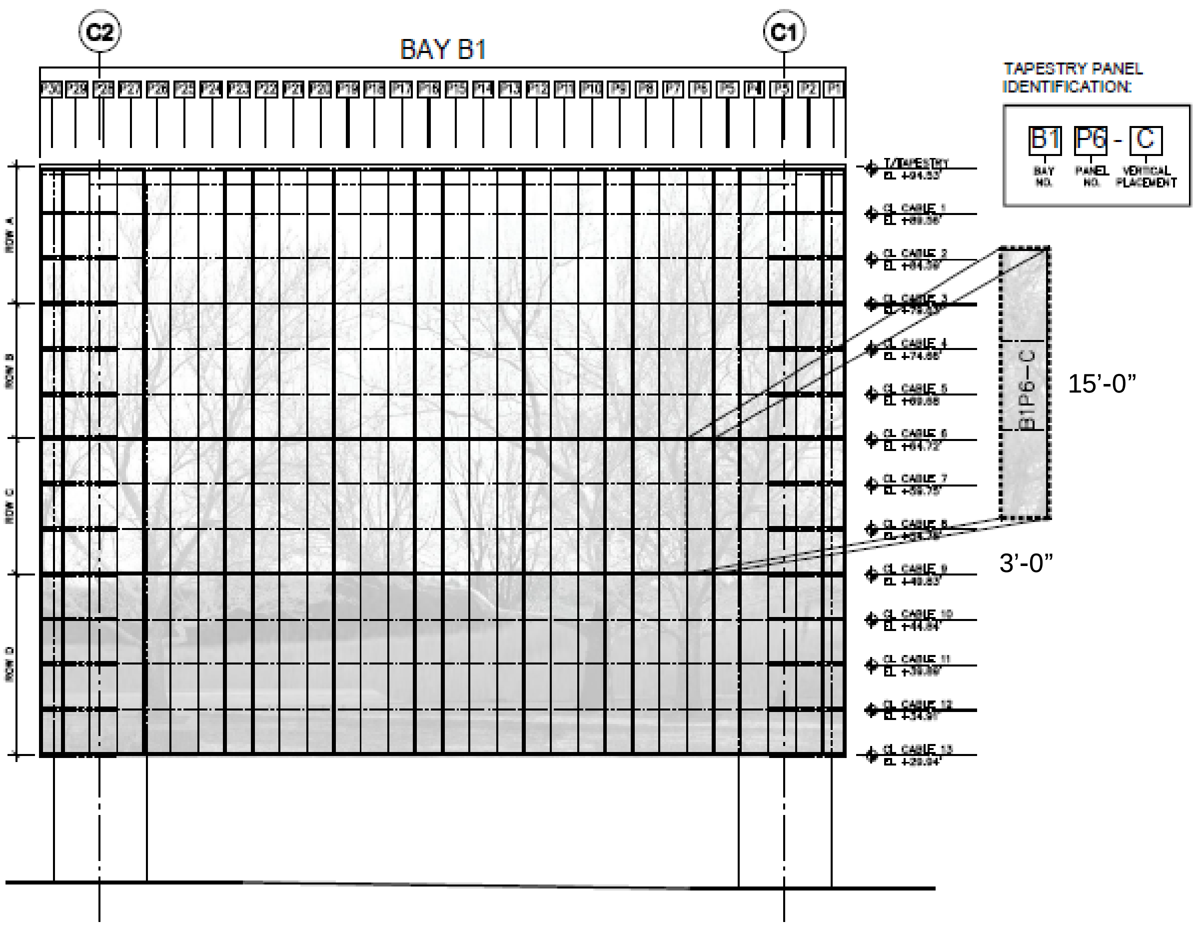
Structural analysis and design of other non-structural elements and their attachment are the responsibility of others.

The enclosed structural calculations are intended for use only for the specific project specified above, and intended for use by experienced and qualified professionals.

Structural stamp & wet signature

TABLE OF CONTENTS

1 TYPICAL TAPESTRY PANEL GENERAL DESIGN DESCRIPTION



A typical Tapestry panel spans approximately 15 feet in height and 3 feet in width. A mesh layout within a panel consists of 1/16" diameter 317L annealed stainless steel vertical twisted structural wires @ 5/8" O.C. braced by double 1/16" 317L annealed stainless steel horizontal structural twisted wires.

Horizontal twisted wires are welded to each vertical twisted wire. The weld between vertical and horizontal twisted wires is designed to support dead, wind, seismic, and thermal loads.

Vertical twisted wires terminate at ½" stainless steel rods at top and bottom. The structural horizontal 1/16" double twisted wires (8" O.C.) terminate at 3/8" stainless steel cables and the remaining horizontal non-structural double twisted wires at the vertical twisted wires.

The tapestry dead load and ice dead load is supported primarily by the 1/16" vertical twisted structural wires and the wind & seismic load (inward and outward) is supported by the double 1/16" horizontal twisted structural wires which terminate at the 3/8" stainless steel cables.

The tapestry art will be constructed from three different size braided wires, those are non-structural wires.

2 Weld Capacity Summary

The design team performed mechanical strength testing on welded wire samples to quantify the breaking loads (lbs) for the various types of weld joints for comparison to the calculated tapestry design loads.

The test values from Element # TOM002-21955M "Mechanical Strength Testing of Welded Samples" have been incorporated into this report on page 10 & 11 for comparison to the calculated weld capacity.

The results below show that even with a factor of safety of 4, the weld capacity is 5 times the maximum load on each weld for the structural wires, and for the art wires, the weld capacity is approximately 8 times the maximum load on each weld.

In conclusion, testing shows the welded joints capacity far exceed the actual loading on each weld.

- Structural wires weld capacity
  The overall capacity of each structural weld is 9.1 pounds after applying a factor of safety of 4. The maximum load on each structural weld is 1.66 pounds.

- Non-Structural wires weld capacity
  The overall capacity of each non-structural weld is 2.95 pounds after applying a factor of safety of 4. The maximum load on each structural weld is 0.37 pounds.

3 LOADING & STRESS DETERMINATION

Dead Loading per E.O.R..

Tapestry Weight for analysis per EOR $DL_t := 20psf$

Tapestry Ice Weight for analysis per EOR $DL_{ti} := 20.64psf$

Wind Loading per Wind Study (RWDI Project No. 1011813), with Porosity Study incorporated (max.)

Wind Loads-Typical Condition
Upper third surface $W_u := 25psf$

Wind Loads-Typical Condition
Middle third surface $W_m := 15psf$

Wind Loads-Typical Condition
Lower third surface $W_l := 10psf$

Wind Loading per Wind Study (RWDI Project No. 1011813), 90 mph, Iw=1.15

Wind Loads-Typical Condition
Upper third surface $W_{in\_u} := 34psf$ $W_{out\_u} := -16psf$

$W_u := W_{in\_u} - W_{out\_u}$ $W_u = 50 \cdot psf$

Wind Loads-Typical Condition
Middle third surface $W_{in\_m} := 30psf$ $W_{out\_m} := -16psf$

$W_m := W_{in\_m} - W_{out\_m}$ $W_m = 46 \cdot psf$

Wind Loads-Typical Condition
Lower third surface $W_{in\_l} := 24psf$ $W_{out\_l} := -12psf$

$W_l := W_{in\_l} - W_{out\_l}$ $W_l = 36 \cdot psf$

Wind Ice Loading per Wind Study (RWDI Project No. 1011813), 75mph, Iw=1.0

Wind Loads-Typical Condition
Upper third surface $W_{in\_u} := 21psf$ $W_{out\_u} := -9psf$

$W_{ui} := W_{in\_u} - W_{out\_u}$ $W_{ui} = 30 \cdot psf$

Wind Loads-Typical Condition
Middle third surface $W_{in\_m} := 18psf$ $W_{out\_m} := -8psf$

$W_{mi} := W_{in\_m} - W_{out\_m}$ $W_{mi} = 26 \cdot psf$

Wind Loads-Typical Condition
Lower third surface $W_{in\_l} := 17psf$ $W_{out\_l} := -7psf$

$W_{li} := W_{in\_l} - W_{out\_l}$ $W_{li} = 24 \cdot psf$

Seismic Loading per chapter 15, ASCE 7-05.

Component response modification factor $R := 3.5$ $C_d := 3$ $\pi_o := 1.75$ Table 15.4-2

Importance factor, Type II $I_p := 1.0$

Spectral acceleration $S_{DS} := 0.163$

Operating weight of panel $W_p := 20 \cdot psf$

Seismic coefficients $C_s := \dfrac{S_{DS}}{\left(\dfrac{R}{I_p}\right)}$ $C_s = 0.0466$

$C_{s\_min} := 0.044 \cdot S_{DS} \cdot I_p$ $C_{s\_min} = 0.007$

Horizontal seismic design force $Fp_{h1} := C_s \cdot W_p$

$\boxed{Fp_{h1} = 0.93 \cdot psf}$

Thermal Expansion of horizontal wire considered within one panel

Length of horizontal $L_h := 36in$

Length of vertical (2 spans) $L_v := 24in$

Area of wire $A_w := \dfrac{\pi}{4} \cdot \left(\dfrac{1}{16} in\right)^2$ $A_w = 0.0030679616 \cdot in^2$

Inertia of wire $I_w := \dfrac{\pi}{64} \cdot \left(\dfrac{1}{16} in\right)^4$ $I_w = 0.0000007490 \cdot in^4$

Coefficient of thermal expansion per deg. F for 100 degrees $CTE := 0.00099$

Total Temperature range, deg. F $\Delta_t := 120$

Temperature mean change , deg. F $\Delta_{tm} := 60$

Change in length in horizontal wire $\Delta_{ex} := \dfrac{CTE \cdot \Delta_{tm} \cdot L_h}{100}$ $\Delta_{ex} = 0.021 \cdot in$ $\Delta_{ex} = 0.54 \cdot mm$

Change in stress in horizontal wire $\zeta := \dfrac{E_{ss} \cdot CTE \cdot \Delta_{tm}}{100}$ $\zeta = 16.632 \cdot ksi$

Tension Force on horizontal wire as a result of the change in length

$T_{\Delta.h} := \zeta \cdot A_w$ $\boxed{T_{\Delta.h} = 51 \cdot lbf}$

Force on vertical wire and shear on weld as a result of the change in length of horizontal wire

$V_{\Delta.w} := \dfrac{48 \cdot \Delta_{ex} \cdot E_{ss} \cdot I_w}{L_v^3}$ $\boxed{V_{\Delta.w} = 0.0016 \cdot lbf}$ Negligable

Determine Tension Loading on vertical 1/16" 316L annealed cables at 5/8" O.C.

Note: 316L material and stress properties are used in the analysis due to availability of such properties, properties of 317L Stainless Steel are equivalent.

Tapestry panel Height, typ.	$H_{tp} := 15ft$	
Tapestry panel width, typ.	$b_t := 3ft$	
Dia. of individual panel horizontal and vertical wire, typ.	$d_{ipw} := \frac{1}{16} in$	
Yeild stress, 316L Stainless Steel.	$F_y := 42ksi$	
Ult. Tensile stress, 316L Stainless Steel.	$F_{ut} := 98.6ksi$	$F_{ut} = 680 \cdot MPa$
Elasticity stress, 316L Stainless Steel.	$E_{ss} := 28000ksi$	$E_{ss} = 193053 \cdot MPa$
Allowable tension stress per wire-DL	$F_{a\_dl} := \min(0.45 \cdot F_y, 0.5 \cdot F_{ut})$	$F_{a\_dl} = 19 \cdot ksi$
Allowable tension stress per wire-WL	$F_{a\_wl} := 1.6 \cdot \min(0.45 \cdot F_y, 0.5 \cdot F_{ut})$	$F_{a\_wl} = 30 \cdot ksi$
Tapestry Weight for analysis per EOR	$DL := 20psf$	
Tapestry Ice Weight for analysis per EOR	$DL_i := 20.64psf$	
Tributary Width & Typical Span	$tw_1 := \frac{5}{8} in$	$L := 16in$

Load combinations per ASCE/SEI 7-05 (ASD):

	D	5.	$D + W$
	$D + D_i$	6.	$D + 0.75 \cdot W$
	$D + 0.7 \cdot D_i + 0.7 \cdot W$	7.	$0.6 \cdot D + 0.7 \cdot D_i + 0.7 \cdot W$

Vertical uniform loading (one span between horizontals):

$\omega_d := (DL) \cdot (tw_1)$ $\qquad \omega_d = 0.0868 \cdot \frac{lbf}{in}$

$\omega_{di} := (DL_i) \cdot (tw_1)$ $\qquad \omega_{di} = 0.0896 \cdot \frac{lbf}{in}$

Vertical reaction at each weld to double horizontal cables:

$P_{DL\_V} := \frac{1}{2} \cdot (DL + DL_i) \cdot (tw_1) \cdot (L)$ $\qquad \boxed{P_{DL\_V} = 1.4111 \cdot lbf}$

Cumalative Vertical loading (tension):

$P_{TDL\_V} := (DL + DL_i) \cdot (tw_1) \cdot (H_{tp})$ $\qquad \boxed{P_{TDL\_V} = 31.7500 \cdot lbf}$

Allowable tension force per verical wire $\qquad T_{all.v} := (F_{a\_dl}) \cdot (A_w)$

$\boxed{T_{all.v} = 58 \cdot lbf} \quad > \quad P_{TDL\_V} = 32 \cdot lbf$ OK

Determine Tension Loading on horizontal 1/16" 316L annealed cables at 16" O.C.

Tapestry Weight for analysis per EOR $DL := 20psf$

Tapestry Ice Weight for analysis per EOR $DL_i := 20.64psf$

Wind Load $W_{in\_u} := 34psf$ $W_{out\_u} := -16psf$

$W_u := W_{in\_u} - W_{out\_u}$ $W_u = 50 \cdot psf$

Tributary Width & Typical Span $tw_2 := 16in$ $L := 3ft$

Horizontal uniform loading-out of plane (one span):

$\omega_w := (W_u) \cdot (tw_2)$ $\omega_w = 5.5556 \cdot \frac{lbf}{in}$ or

$\omega_{wp} := \omega_w \cdot \left(\frac{5}{8} in\right)$ $\omega_{wp} = 3 \cdot lbf$ at 5/8" O.C.

Tension on each horizontal wire per attached (14% sag):

$T_{w.h} := \frac{151.12lbf}{4} \cdot \left(\frac{16in}{12in}\right)$ $\boxed{T_{w.h} = 50 \cdot lbf}$

Shear on each weld to vertical wire:

$P_{v.w} := \frac{T_{w.h}}{\frac{(L)}{tw_1}}$ $\boxed{P_{v.w} = 0.87 \cdot lbf}$

Allowable tension force per horizontal wire $T_{all.v} := (F_{a\_wl}) \cdot (A_w)$

$\boxed{T_{all.v} = 93 \cdot lbf}$ > $T_{w.h} = 50 \cdot lbf$ OK

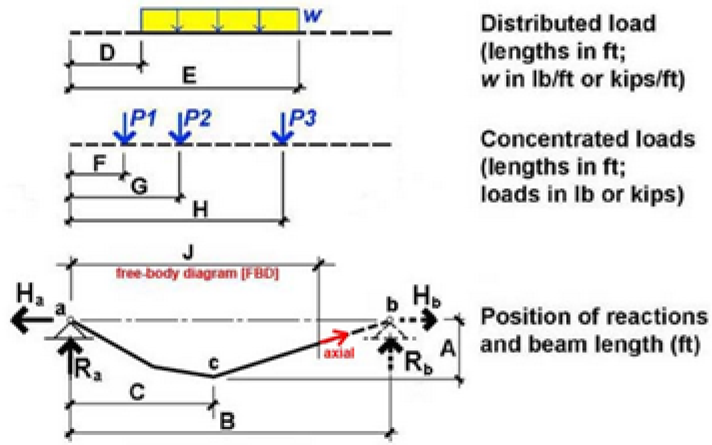


Fig. 1. *Cable geometry (lengths) and magnitude of loads*

Update

Positions of loads and reactions (ft)

Sag	Span	Sag point	Uniform load position		Point load positions			FBD
A	B	C	D	E	F	G	H	J
0.42	3	1.5	0	3	1	1.25	1.5	0.1

Loads (use kips/ft and kips or lb/ft and lb)

w	P1	P2	P3
50	0	0	0

Vert reaction at "a"	Vert reaction at "b"	Horiz reaction at "a,b"	Axial force(s) at FBD	FBD Height
75	75	133.93	151.12	0.05

Weld Capacity for Structural 7x7 Twisted Wires per calculation and testing

Tensile strength of E316L-16 electrode	$Fu_{E316} := 98ksi$	$Fu_{E316} = 676 \cdot MPa$
Yeild stress, 316L Stainless Steel.	$F_y := 42ksi$	$F_y = 290 \cdot MPa$

Allowable weld @ 20% total contact

$$F_a := 0.30 \cdot F_{ut} \cdot \left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right) \cdot (20\%) \qquad F_a = 16.49 \cdot lbf$$

Allowable shear of base metal @ 20% total contact

$$F_v := 0.40 \cdot F_y \cdot \left[\left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right)\right] \cdot (20\%) \qquad F_v = 13.13 \cdot lbf$$

Ultimate weld @ 20% total contact

$$F_{au} := F_{ut} \cdot \left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right) \cdot (20\%) \qquad F_{au} = 54.96 \cdot lbf$$

Ultimate shear of base metal @ 20% total contact

$$F_{vu} := F_y \cdot \left[\left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right)\right] \cdot (20\%) \qquad F_{vu} = 32.81 \cdot lbf$$

Allowable Weld Capacity	$V_{all\_s} := \min(F_a, F_v)$	$V_{all\_s} = 13.125 \cdot lbf$
Allowable Weld Capacity (Single to Double 7x7 Twisted)	$V_{all\_d} := \min(2 \cdot F_a, 2 \cdot F_v)$	$V_{all\_d} = 26.250 \cdot lbf$
Ultimate Weld Capacity	$V_{alt\_s} := \min(F_{au}, F_{vu})$	$V_{alt\_s} = 32.813 \cdot lbf$
Ultimate Weld Capacity (Single to Double 7x7 Twisted)	$V_{alt\_d} := \min(2 \cdot F_{au}, 2 \cdot F_{vu})$	$V_{alt\_d} = 65.625 \cdot lbf$
Average Tested Weld Capacity - (Structural Torque shear Test)	$V_{ult\_test1} := 36.4lbf$	(2B Joint Type 1, 316L) *
Average Tested Weld Capacity - (Structural Peel Test)	$V_{ult\_test2} := 42.2lbf$	(2B Joint Type 1, 316L) *
Allowable Weld Capacity from Testing with factor of safety of 4	$V_{all\_test} := \min\left(\frac{1}{4} \cdot V_{ult\_test1}, \frac{1}{4} \cdot V_{ult\_test2}\right)$	

$$V_{all\_test} = 9.100 \cdot lbf \quad > \quad P_{Res.w} := \sqrt{(P_{DL\_V})^2 + (P_{v.w})^2} \quad P_{Res.w} = 1.66 \cdot lbf \quad \text{OK}$$

*Values obtained from Element Report # TOM002-21955M "Mechanical Strength Testing of Welded Samples"

Weld Capacity for Art Braided Wires per calculation and testing

Average spacing of Art welds in any direction	$l_{aw} := 1in$	
Tensile strength of E316L-16 electrode	$Fu_{E316} := 98ksi$	$Fu_{E316} = 676 \cdot MPa$
Yeild stress, 316L Stainless Steel.	$F_y := 42ksi$	$F_y = 290 \cdot MPa$
Shear per art weld (maximum):	$P_{d.aw} := (DL + DL_i) \cdot (l_{aw}) \cdot (l_{aw})$	$P_{d.aw} = 0.2822 \cdot lbf$
Tension per art weld (maximum):	$P_{w.aw} := (W_{in\_u}) \cdot (l_{aw}) \cdot (l_{aw})$	$P_{w.aw} = 0.2361 \cdot lbf$

Allowable weld @ 20% total contact

$$F_a := 0.30 \cdot F_{ut} \cdot \left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right) \cdot (20\%) \qquad F_a = 16.49 \cdot lbf$$

Allowable shear of base metal @ 20% total contact

$$F_v := 0.40 \cdot F_y \cdot \left[\left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right)\right] \cdot (20\%) \qquad F_v = 13.13 \cdot lbf$$

Ultimate weld @ 20% total contact

$$F_{au} := F_{ut} \cdot \left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right) \cdot (20\%) \qquad F_a = 16.49 \cdot lbf$$

Ultimate shear of base metal @ 20% total contact

$$F_{vu} := F_y \cdot \left[\left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right)\right] \cdot (20\%) \qquad F_v = 13.13 \cdot lbf$$

Allowable Weld Capacity	$V_{all\_s} := \min(F_a, F_v)$	$V_{all\_s} = 13.125 \cdot lbf$
Ultimate Weld Capacity	$V_{alt\_s} := \min(F_{au}, F_{vu})$	$V_{alt\_s} = 32.813 \cdot lbf$
Average Tested Weld Capacity - (Art Torque shear Test)	$V_{ult\_test1} := 12.4lbf$	(3B Joint Type 2, 316L) *
Average Tested Weld Capacity - (Art Peel Test)	$V_{ult\_test2} := 11.8lbf$	(3B Joint Type 2, 316L) *
Allowable Weld Capacity from Testing with factor of safety of 4	$V_{all\_test} := \min\left(\frac{1}{4} \cdot V_{ult\_test1}, \frac{1}{4} \cdot V_{ult\_test2}\right)$	

$$V_{all\_test} = 2.950 \cdot lbf \quad > \quad V_{Res.w} := \sqrt{(P_{d.aw})^2 + (P_{w.aw})^2} \qquad V_{Res.w} = 0.37 \cdot lbf \qquad \text{OK}$$

*Values obtained from Element Report # TOM002-21955M “Mechanical Strength Testing of Welded Samples”

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Tomas Osinski
Tomas Osinski Design
4240 Glenmuir Ave
Los Angeles, CA, 90065

Date: February 3, 2014
Author: Hugo A. Menendez

Element Report #: TOM002-21955M

Mechanical Strength Testing of Welded Samples

Prepared by:

Hugo A. Menendez, MS, P.E.
Department Manager, Failure Analysis, Metallurgist
Element Materials Technology – Huntington Beach

INTRODUCTION

Element personnel were asked to provide mechanical and metallurgical testing services to Tomas Osinski Design in support of the Eisenhower Memorial Tapestry Project.

It should be noted that alloy 317L stainless steel which was selected by the design team as the optimum material for the tapestry was only available in the structural wire form at the time of testing. None of the art braided wire was available in alloy 317L at the time of testing. Alloy 316L stainless steel which had previously been a candidate alloy was available in all forms and was included in the study for comparison purposes but is not being considered as the preferred alloy for construction of the tapestries.

OBJECTIVE

The objective of this study was to quantify the breaking loads (lbs) for the various types of weld joints / samples provided for comparison to the calculated tapestry design loads presented in the *Weld Capacity Report* from Najjarine Structures. The testing was also intended to provide numerical data regarding weld strength values following corrosion testing. The samples submitted represent as welded and salt spray tested (ASTM G85 – 11 Annex A4, Cycle A4.4.1) stainless steel braided and twisted wire joints which will be used to construct the Eisenhower Memorial Tapestries.

OVERVIEW OF TEST SAMPLES

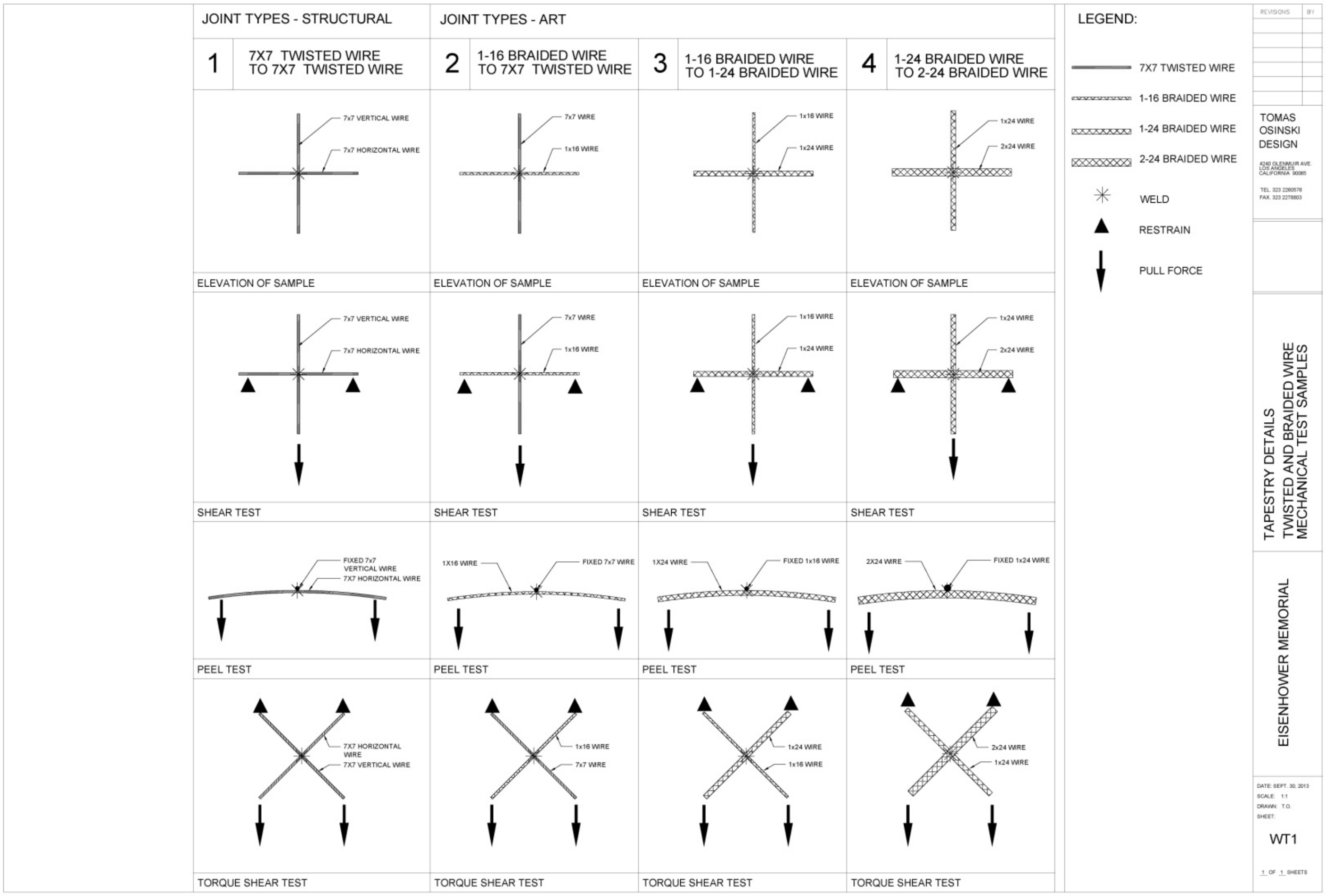
The tapestries will be constructed from four wire types – one structural twisted wire and three nonstructural "art" braided wires. The schematic on the following page shows the four weld joint types which will be used to construct the tapestries. The schematic also shows diagrams representing the mechanical strength tests which were performed on as-welded samples along with duplicate samples which had been corrosion tested.

Different weld settings were used for each of the joint types. Mechanical strength tests were performed on as-welded samples to establish base line properties. The same mechanical strength tests were performed on duplicate samples after exposing them to a 1000 hour SO_2 salt spray (fog) test.

The test samples included Type 1 for the 317L and Type 1 for the 316L structural wires. As noted above, only alloy 316L was provided for the art braided weld joint samples (Type 2, Type 3 and Type 4 weld joints). See diagram on adjacent page.

DIAGRAM ILLUSTRATING THE VARIOUS WELD JOINT TYPES AND MECHANICAL STRENGTH TESTS PERFORMED

EXHIBIT 3



The torque shear test diagram is not reflective of how the actual test was performed in that the actual joints were loaded from one side in order to create a more severe unbalanced load condition. Figure 2, Figure 3, and Figure 4 are macro photographs showing a representative sample from each type of mechanical strength test performed.

SUMMARY of MECHANICAL STRENGTH TESTING PERFORMED

Tensile tests were performed on 150 welded joints. Baseline measurements (as-welded samples) were made for each weld joint type by testing 15 welds. The baseline testing performed consisted of three different loading scenarios (Shear, Peel and Torque Shear) using five samples for each type of test.

The same tests (Shear, Peel and Torque Shear) were performed on duplicate welded joints which had been exposed to an SO_2 salt spray test per ASTM G85 – 11 Annex A4, Cycle A4.4.1 for 1000 hours. The salt spray test samples were coated with lamp black prior to the test exposure period and were stressed during testing. Approximately two pounds of dead weight were attached to each sample for the duration of the 1000 hour salt spray test.

The average measured values for each type of test performed, both before and after SO_2 salt spray testing, are summarized for review on page 6. Each reported average value on the Summary Tables represents five individual mechanical strength tests. The mechanical strengths reported were measured using a table top tensile test machine as shown in Figure 1.

Macro photographs of the various tensile test configurations are presented in Figure 2, Figure 3 and Figure 4 for review. The results for each individual tests performed are presented for review on page 7, page 8, page 9, page 10 and page 11.

The measured weld joint mechanical strength results reflect the variability in weld strength which was anticipated due to the unique nature of welding braided and twisted wires. The number of individual wires that are in contact with one another when the weld is made can vary. This has a direct effect on the number of wires welded and accounts for the weld strength variations observed.

STRUCTURAL WIRE WELD STRENGTH RESULTS (TYPE 316L and Type 317L)

The testing performed on the welded Type 1 joints made from alloy 316L and alloy 317L showed no degradation in mechanical strength between the as-welded samples and the 1000 hour SO_2 salt spray tested samples. This conclusion is based on the strength values measured, as well as observations made during numerous optical and Scanning Electron Microscope examinations which were performed on the broken joints after strength testing.

The measured strength values clearly show that the structural wire welds were the strongest with average measured breaking strengths of 49 lbs (as welded) – 52 lbs (after salt fog testing) for the 317L alloy structural 7x7 twisted wire to 317L structural 7x7 twisted wire and 39 lbs (as welded) – 51 lbs (after salt fog testing) for the 316L alloy structural 7x7 twisted wire to 316L structural 7x7 twisted wire.

Each average value reported above represents the calculated average of the 15 individual weld tests for a specific alloy / joint type and test condition, i.e., 317L alloy Type 1 joint as-welded, or 317L alloy Type 1 joint after salt spray testing. In nearly all cases the salt fog tested samples exhibited higher average breaking values than the as-welded samples which is attributed to the variation in the number of welded wires described previously. The reported welding parameters are presented in the body of the report.

NON STRUCTURAL ART WELD STRENGTH RESULTS

The alloy 316L art wire welds showed lower breaking strengths than the structural wire welds as evidenced by the joint Type 2, 3 and 4 weld joint summary tables. This result was not unexpected in that the weld setting parameters were chosen to optimize the weld quality while minimizing the heat tint taking into account the lower load carrying requirements for the art wires relative to the structural wires.

Alloy 317L was selected by the design team based on previous corrosion performance of solid wires. Alloy 316L for twisted and braided cables was tested for mechanical strength and corrosion as a baseline comparison with alloy 317L.

Macro, stereo and SEM micrographs detailing the laboratory observations are presented for review.

TENSILE TESTING SUMMARY TABLES

JOINT TYPE 1 - 317L Structural 7x7 Twisted Wire to 317L Structural 7x7 Twisted Wire			
Sample Description	Shear Average:	Peel Average:	Torque Shear Average
As - Welded	50.4 lbs	53.8 lbs	42.0 lbs
After Corrosion Test	57.0 lbs	50.8 lbs	47.2 lbs

JOINT TYPE 1 - 316L Structural 7x7 Twisted Wire to 316L Structural 7x7 Twisted Wire			
Sample Description	Shear Average:	Peel Average:	Torque Shear Average
As - Welded	37.8 lbs	42.2 lbs	36.4 lbs
After Corrosion Test	52.4 lbs	57.8 lbs	42.0 lbs

JOINT TYPE 2 - 316L Art 1-16 Braided Wire to 316L Structural 7x7 Twisted Wire			
Sample Description	Shear Average:	Peel Average:	Torque Shear Average
As - Welded	20.0 lbs	11.8 lbs	12.4 lbs
After Corrosion Test	15.2 lbs	18.0 lbs	14.6 lbs

JOINT TYPE 3 - 316L Art 1-16 Braided Wire to 316L Art 1-24 Braided Wire			
Sample Description	Shear Average:	Peel Average:	Torque Shear Average
As - Welded	27.2 lbs	21.6 lbs	18.2 lbs
After Corrosion Test	21.4 lbs	26.4 lbs	14.2 lbs

JOINT TYPE 4 - 316L Art 1-42 Braided Wire to 316L Art 2-24 Braided Wire			
Sample Description	Shear Average:	Peel Average:	Torque Shear Average
As - Welded	21.0 lbs	21.8 lbs	21.6 lbs
After Corrosion Test	28.4 lbs	28.8 lbs	18.2 lbs

MECHANICAL STRENGTH TEST RESULTS FOR:

JOINT TYPE 1 - 317L Structural 7x7 Twisted Wire to 317L Structural 7x7 Twisted Wire

Test Description	Sample ID As-Welded	As-welded Breaking Load (lbs)	Sample ID Corrosion Tested	Corrosion Tested Breaking Load (lbs)
Shear Weld Strength Sample	**# 1**	37 lbs	**# 19**	68 lbs
Shear Weld Strength Sample	**# 2**	59 lbs	**# 20**	52 lbs
Shear Weld Strength Sample	**# 3**	49 lbs	**# 21**	66 lbs
Shear Weld Strength Sample	**# 4**	61 lbs	**# 22**	63 lbs
Shear Weld Strength Sample	**# 5**	46 lbs	**# 23**	36 lbs
	Average (5)	**50.4 lbs**	**Average (5)**	**57 lbs**
Peel Weld Strength Sample	**# 7**	50 lbs	**# 25**	42 lbs
Peel Weld Strength Sample	**# 8**	47 lbs	**# 26**	61 lbs
Peel Weld Strength Sample	**# 9**	53 lbs	**# 27**	52 lbs
Peel Weld Strength Sample	**# 10**	64 lbs	**# 28**	46 lbs
Peel Weld Strength Sample	**# 11**	55 lbs	**# 29**	53 lbs
	Average (5)	**53.8 lbs**	**Average (5)**	**50.8** lbs
Torque Shear Weld Strength Sample	**# 13**	41 lbs	**# 30**	43 lbs
Torque Shear Weld Strength Sample	**# 14**	65 lbs	**# 31**	48 lbs
Torque Shear Weld Strength Sample	**# 15**	40 lbs	**# 32**	41 lbs
Torque Shear Weld Strength Sample	**# 16**	29 lbs	**# 33**	56 lbs
Torque Shear Weld Strength Sample	**# 17**	35 lbs	**# 34**	48 lbs
	Average (5)	**42 lbs**	**Average (5)**	**47.2** lbs
Average of 15 welds from each column		**48.7 lbs**		**51.7 lbs**

Weld settings reported to Element: Power – 38%, up-ramp 1ms, time 1ms, pressure 10 lbs

MECHANICAL STRENGTH TEST RESULTS FOR:

JOINT TYPE 1 - 316L Structural 7x7 Twisted Wire to 316L Structural 7x7 Twisted Wire

Test Description	Sample ID As-Welded	As-welded Breaking Load (lbs)	Sample ID Corrosion Tested	Corrosion Tested Breaking Load (lbs)
Shear Weld Strength Sample	**# 51**	37 lbs	**# 69**	65 lbs
Shear Weld Strength Sample	**# 52**	49 lbs	**# 70**	43 lbs
Shear Weld Strength Sample	**# 53**	34 lbs	**# 71**	53 lbs
Shear Weld Strength Sample	**# 54**	35 lbs	**# 72**	47 lbs
Shear Weld Strength Sample	**# 55**	34 lbs	**# 73**	54 lbs
	Average (5)	**37.8** lbs	**Average (5)**	**52.4** lbs
Peel Weld Strength Sample	**# 57**	44 lbs	**# 75**	82 lbs
Peel Weld Strength Sample	**# 58**	36 lbs	**# 76**	37 lbs
Peel Weld Strength Sample	**# 59**	42 lbs	**# 77**	60 lbs
Peel Weld Strength Sample	**# 60**	37 lbs	**# 78**	58 lbs
Peel Weld Strength Sample	**# 61**	52 lbs	**# 79**	52 lbs
	Average (5)	**42.2** lbs	**Average (5)**	**57.8** lbs
Torque Shear Weld Strength Sample	**# 63**	28 lbs	**# 81**	60 lbs
Torque Shear Weld Strength Sample	**# 64**	47 lbs	**# 82**	52 lbs
Torque Shear Weld Strength Sample	**# 65**	26 lbs	**# 83**	39 lbs
Torque Shear Weld Strength Sample	**# 66**	29 lbs	**# 84**	29 lbs
Torque Shear Weld Strength Sample	**# 67**	52 lbs	**# 85**	30 lbs
	Average (5)	**36.4** lbs	**Average (5)**	**42.0** lbs
Average of 15 welds in each column		**38.8 lbs**		**50.7 lbs**

Weld settings reported to Element: Power – 38%, up-ramp 1ms, time 1ms, pressure 10 lbs

MECHANICAL STRENGTH TEST RESULTS FOR:

JOINT TYPE 2 - 316L Art 1-16 Braided Wire to 316L Structural 7x7 Twisted Wire

Test Description	Sample ID As-Welded	As-welded Breaking Load (lbs)	Sample ID Corrosion Tested	Corrosion Tested Breaking Load (lbs)
Shear Weld Strength Sample	**# 101**	14 lbs	**# 119**	18 lbs
Shear Weld Strength Sample	**# 102**	9 lbs	**# 120**	6 lbs
Shear Weld Strength Sample	**# 103**	21 lbs	**# 121**	21 lbs
Shear Weld Strength Sample	**# 104**	30 lbs	**# 122**	13 lbs
Shear Weld Strength Sample	**# 105**	26 lbs	**# 123**	18 lbs
	Average (5)	**20** lbs	**Average (5)**	**15.2** lbs
Peel Weld Strength Sample	**# 107**	8 lbs	**# 125**	12 lbs
Peel Weld Strength Sample	**# 108**	23 lbs	**# 126**	31 lbs
Peel Weld Strength Sample	**# 109**	9 lbs	**# 127**	17 lbs
Peel Weld Strength Sample	**# 110**	13 lbs	**# 128**	14 lbs
Peel Weld Strength Sample	**# 111**	6 lbs	**# 129**	16 lbs
	Average (5)	**11.8** lbs	**Average (5)**	**18** lbs
Torque Shear Weld Strength Sample	**# 113**	8 lbs	**# 131**	19 lbs
Torque Shear Weld Strength Sample	**# 114**	26 lbs	**# 132**	30 lbs
Torque Shear Weld Strength Sample	**# 115**	11 lbs	**# 133**	12 lbs
Torque Shear Weld Strength Sample	**# 116**	17 lbs	**# 134**	7 lbs
Torque Shear Weld Strength Sample	**# 117***	0 lbs	**# 135**	5 lbs
	Average (5)	**12.4** lbs	**Average (5)**	**14.6** lbs
Average of 15 welds in each column		**14.7 lbs**		**15.9 lbs**

*Broke while being manipulated into fixture for testing.

Weld settings reported to Element: Power – 33%, up-ramp 1ms, time 1ms, pressure 10 lbs

MECHANICAL STRENGTH TEST RESULTS FOR:

JOINT TYPE 3 - 316L Art 1-16 Braided Wire to 316L Art 1-24 Braided Wire

Test Description	Sample ID	As-welded Breaking Load (lbs)	Sample ID Corrosion Tested	Breaking Load (lbs) after 1000 hrs
Shear Weld Strength Sample	**# 151**	19 lbs	**# 169**	18 lbs
Shear Weld Strength Sample	**# 152**	22 lbs	**# 170**	38 lbs
Shear Weld Strength Sample	**# 153**	26 lbs	**# 171**	27 lbs
Shear Weld Strength Sample	**# 154**	41 lbs	**# 172**	24 lbs
Shear Weld Strength Sample	**# 155**	28 lbs	**# 173***	0 lbs
	Average	**27.2** lbs	**Average**	**21.4** lbs
Peel Weld Strength Sample	**# 157**	13 lbs	**# 175**	44 lbs
Peel Weld Strength Sample	**# 158**	25 lbs	**# 176**	15 lbs
Peel Weld Strength Sample	**# 159**	18 lbs	**# 177**	34 lbs
Peel Weld Strength Sample	**# 160**	14 lbs	**# 178**	19 lbs
Peel Weld Strength Sample	**# 161**	38 lbs	**# 179**	20 lbs
Average	**Average**	**21.6** lbs	**Average**	**26.4** lbs
Torque Shear Weld Strength Sample	**# 163**	16 lbs	**# 181**	26 lbs
Torque Shear Weld Strength Sample	**# 164**	27 lbs	**# 182**	10 lbs
Torque Shear Weld Strength Sample	**# 165**	10 lbs	**# 183**	12 lbs
Torque Shear Weld Strength Sample	**# 166**	26 lbs	**# 184**	13 lbs
Torque Shear Weld Strength Sample	**# 167**	12 lbs	**# 185**	10 lbs
Average	**Average**	**18.2** lbs	**Average**	**14.2** lbs
Average of 15 welds in each column		**22.3 lbs**		**20.7 lbs**

*Was received from Anchem Laboratories already separated.

Weld settings reported to Element: Power – 50%, up-ramp 1ms, time 1ms, pressure 10 lbs

MECHANICAL STRENGTH TEST RESULTS FOR:

JOINT TYPE 4 - 316L Art 1-42 Braided Wire to 316L Art 2-24 Braided Wire

Test Description	Sample ID	As-welded Breaking Load (lbs)	Sample ID Corrosion Tested	Breaking Load (lbs) after 1000 hrs
Shear Weld Strength Sample	**# 201**	21 lbs	**# 219**	29 lbs
Shear Weld Strength Sample	**# 202**	29 lbs	**# 220**	32 lbs
Shear Weld Strength Sample	**# 203**	25 lbs	**# 221**	27 lbs
Shear Weld Strength Sample	**# 204**	8 lbs	**# 222**	32 lbs
Shear Weld Strength Sample	**# 205**	22 lbs	**# 223**	22 lbs
	Average	**21** lbs	**Average**	**28.4** lbs
Peel Weld Strength Sample	**# 207**	17 lbs	**# 225**	33 lbs
Peel Weld Strength Sample	**# 208**	28 lbs	**# 226**	24 lbs
Peel Weld Strength Sample	**# 209**	17 lbs	**# 227**	24 lbs
Peel Weld Strength Sample	**# 210**	29 lbs	**# 228**	31 lbs
Peel Weld Strength Sample	**# 211**	18 lbs	**# 229**	32 lbs
	Average	**21.8** lbs	**Average**	**28.8** lbs
Torque Shear Weld Strength Sample	**# 213**	31 lbs	**# 231**	23 lbs
Torque Shear Weld Strength Sample	**# 214**	18 lbs	**# 232**	30 lbs
Torque Shear Weld Strength Sample	**# 215**	23 lbs	**# 233**	12 lbs
Torque Shear Weld Strength Sample	**# 216**	15 lbs	**# 234**	9 lbs
Torque Shear Weld Strength Sample	**# 217**	21 lbs	**# 235**	17 lbs
	Average	**21.6** lbs	**Average**	**18.2** lbs
Average of 15 welds in each column		**21.5 lbs**		**25.1 lbs**

Weld settings reported to Element: Power – 70%, up-ramp 2ms, time 1ms, pressure 10 lbs

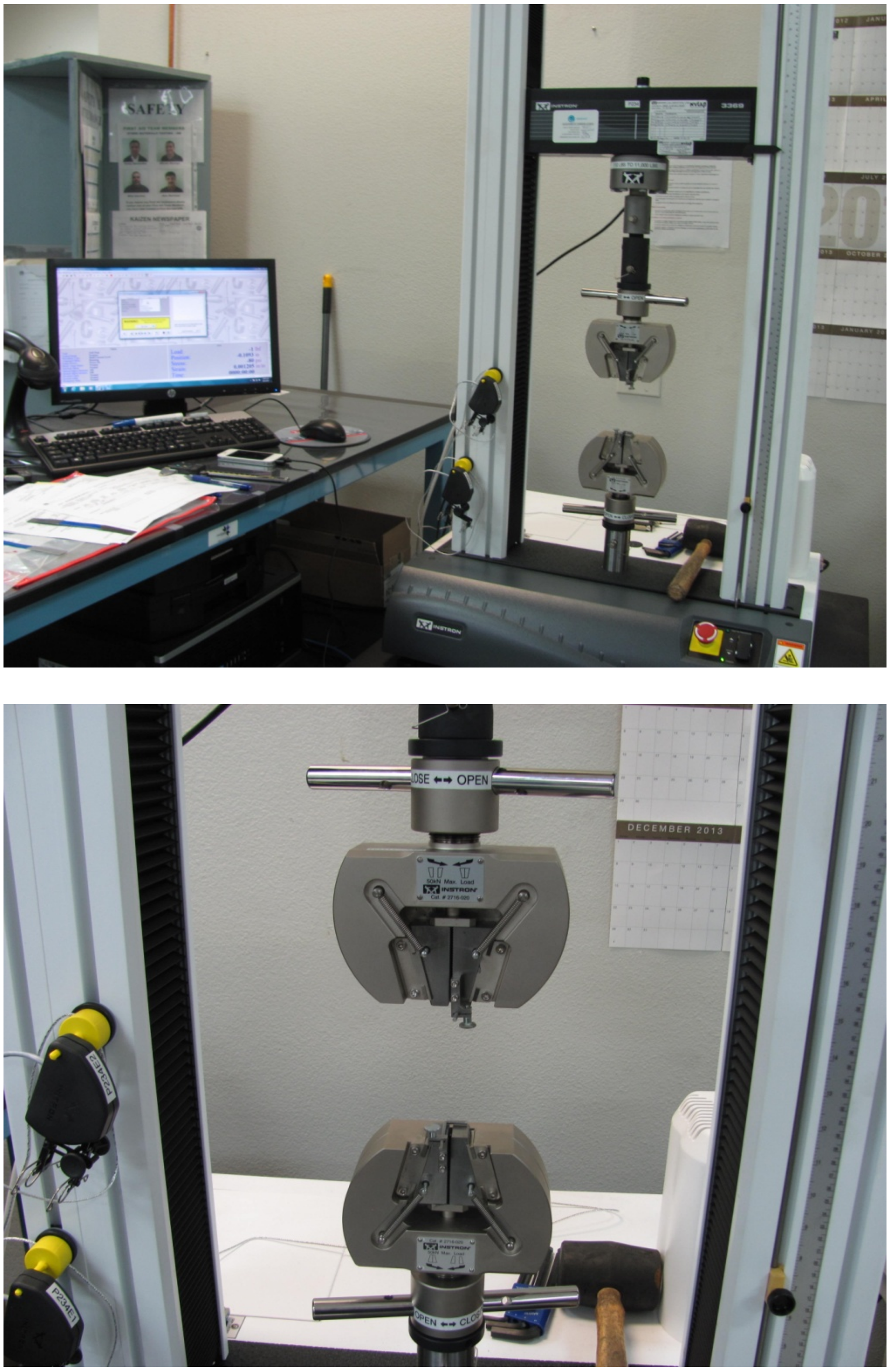


Figure 1- Macro photographs showing the table top Instron Tensile Test machine used to measure the weld joint breaking strengths.

Figure 2 - Macro photograph showing a shear weld strength sample test prior to applying the tensile load.

Figure 3 - Macro photograph showing a peel weld strength sample just prior to testing.

Figure 4 - Macro photograph showing a torque shear weld strength sample during testing.

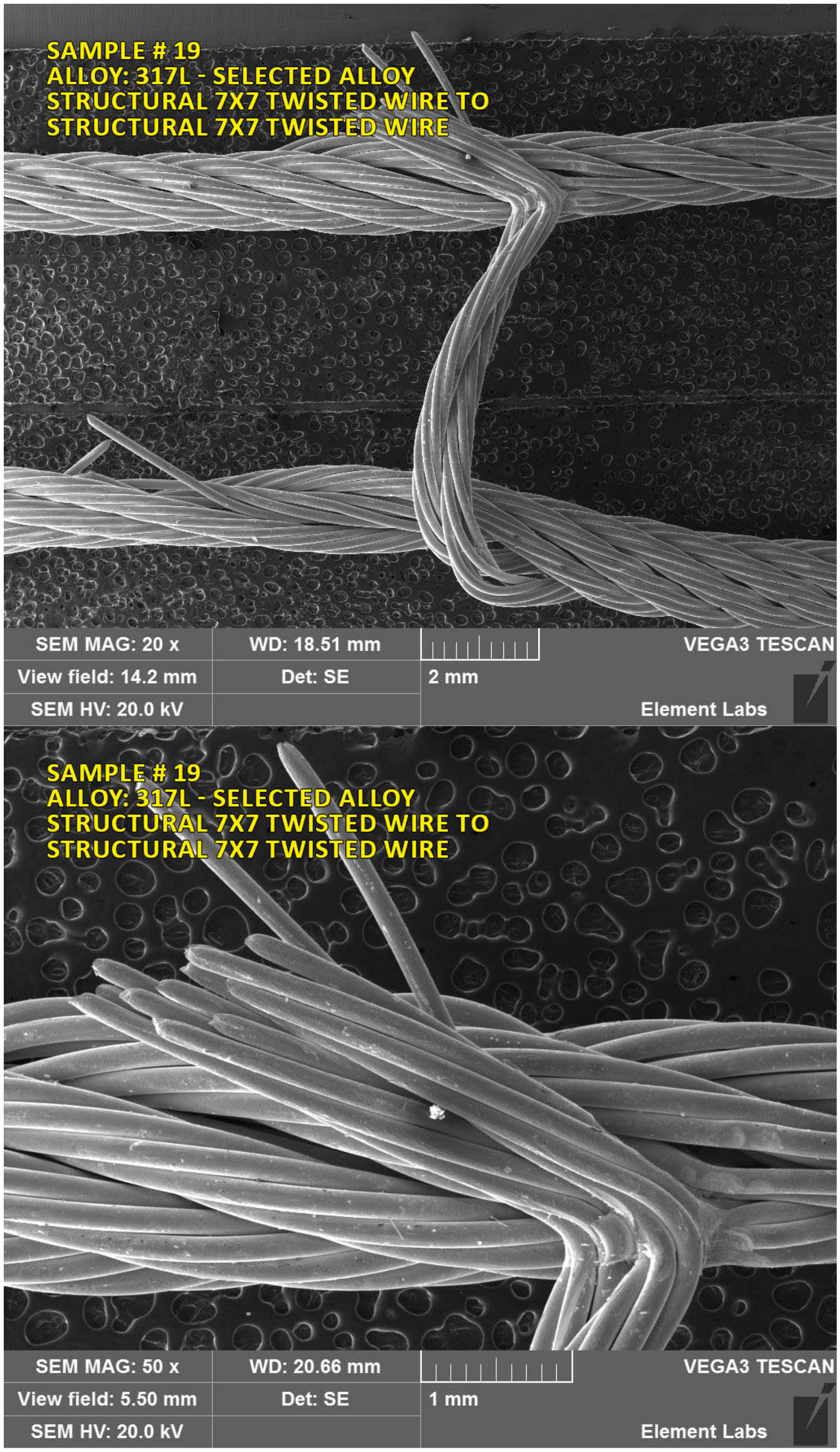


Figure 5 - SEM micrographs showing Sample #19 (Joint Type 1) after corrosion and mechanical strength testing. Note that the fracture did not occur at the weld and that two strands are still attached between the structural members after the breaking load was measured.

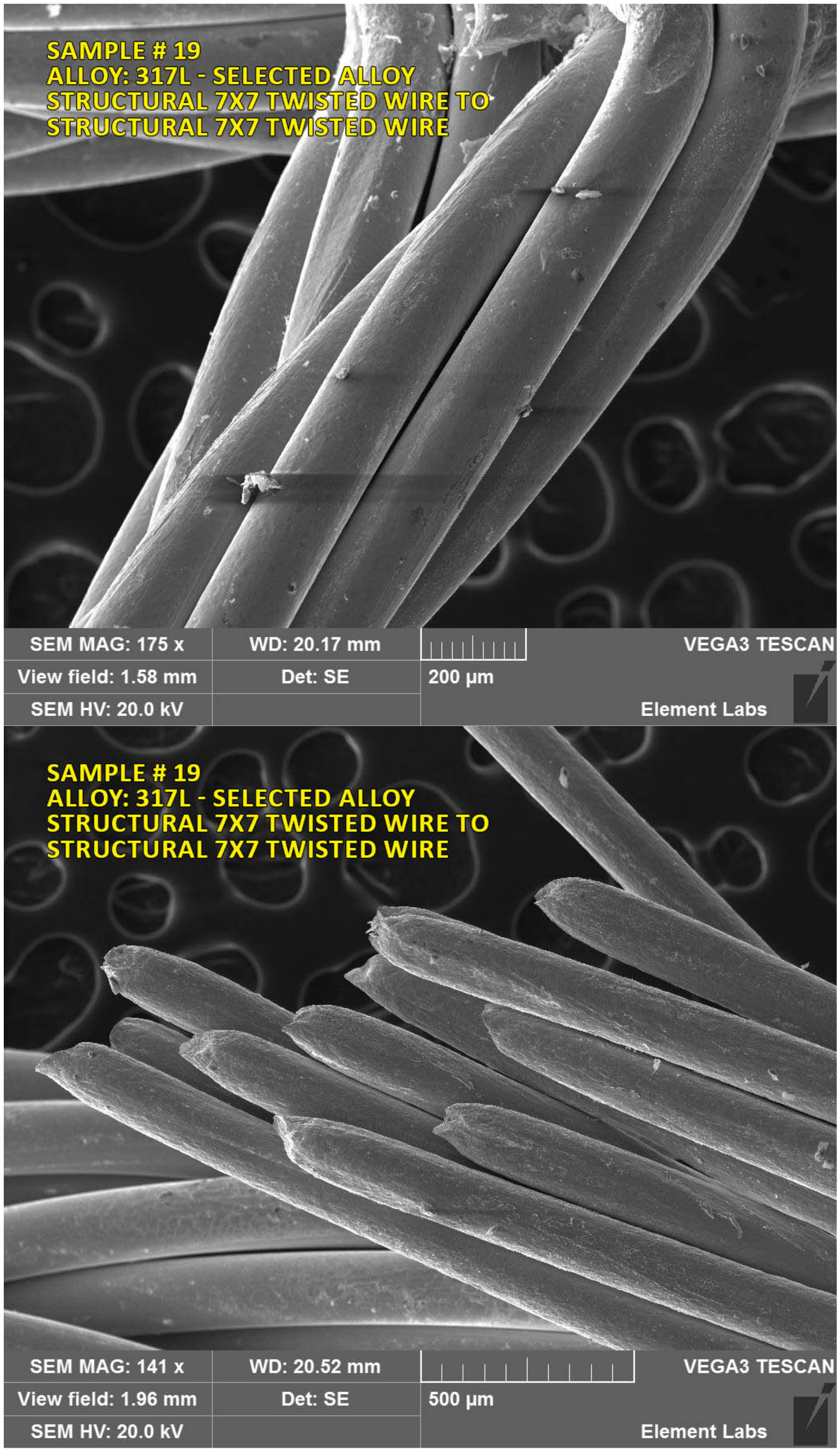
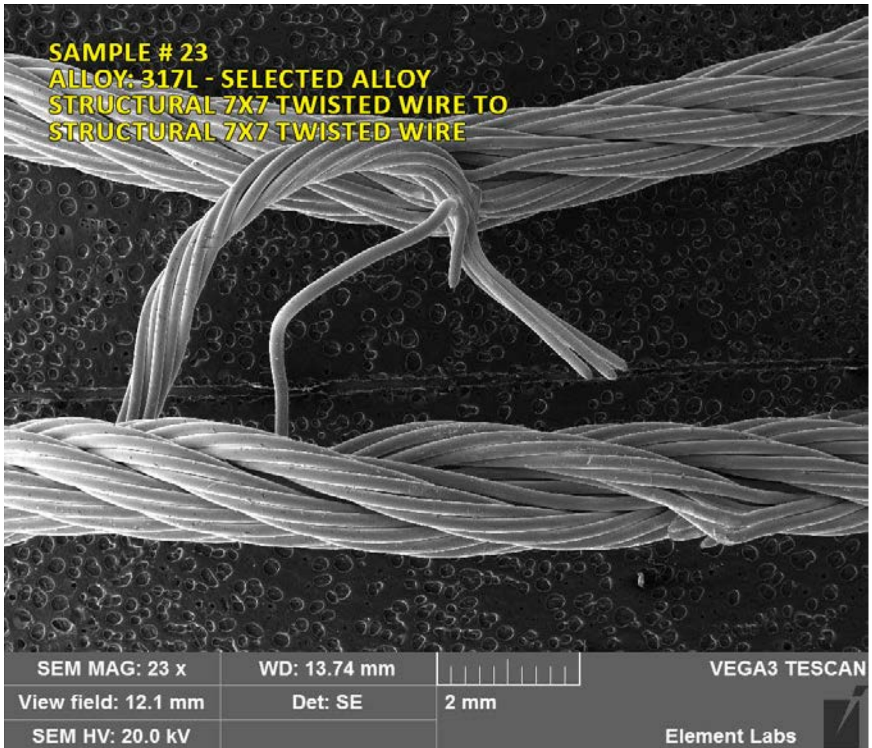


Figure 6 - SEM micrographs (Sample #19) showing the absence of pitting on the wires adjacent to the weld (upper image) and the ductile overload nature of the wire fractures (lower image). No notable corrosion was observed on this or any of the other alloy 317L samples examined.



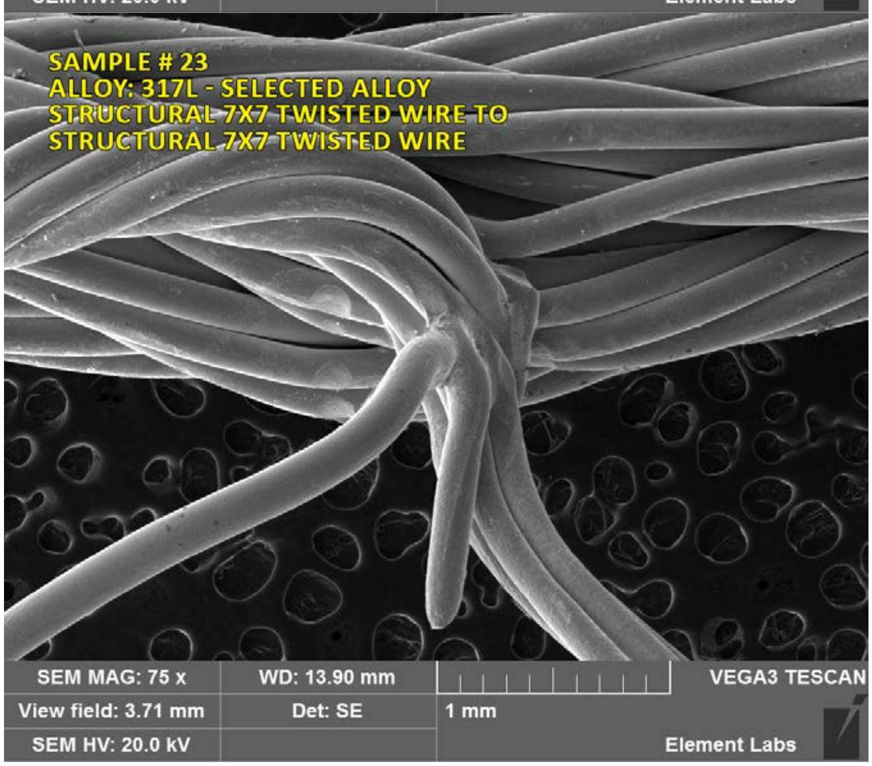


Figure 7 - SEM micrograph showing Sample #23 (Joint Type 1) after corrosion and mechanical strength testing. The majority of the wire breaks occurred away from the weld and one strand is still attached between the two structural members. No evidence of pitting corrosion was observed.

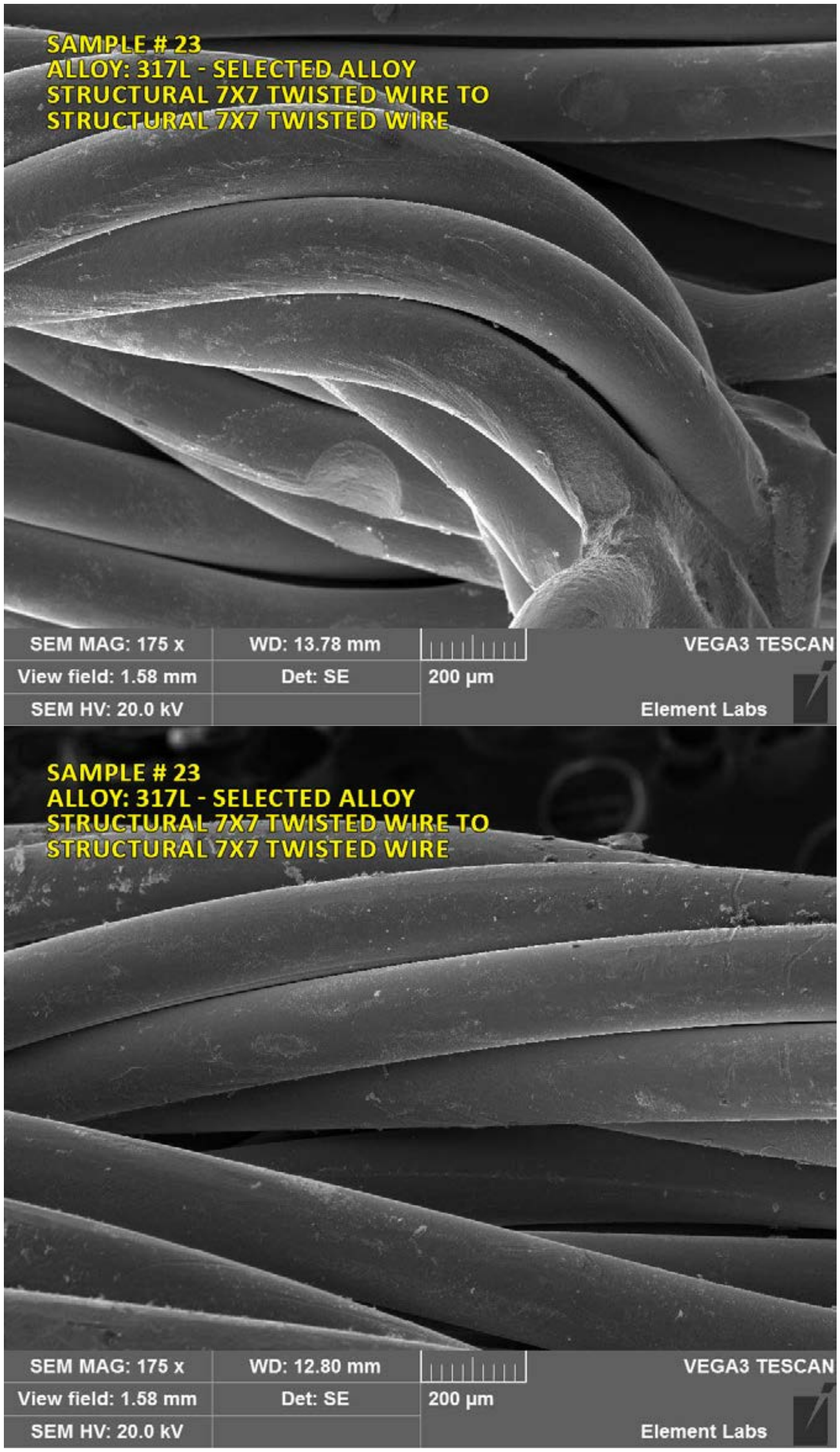


Figure 8 - SEM micrographs (Sample #23) showing the typical alloy 317L wire surface appearance adjacent to the weld after 1000 hours of salt spray exposure and mechanical strength testing.

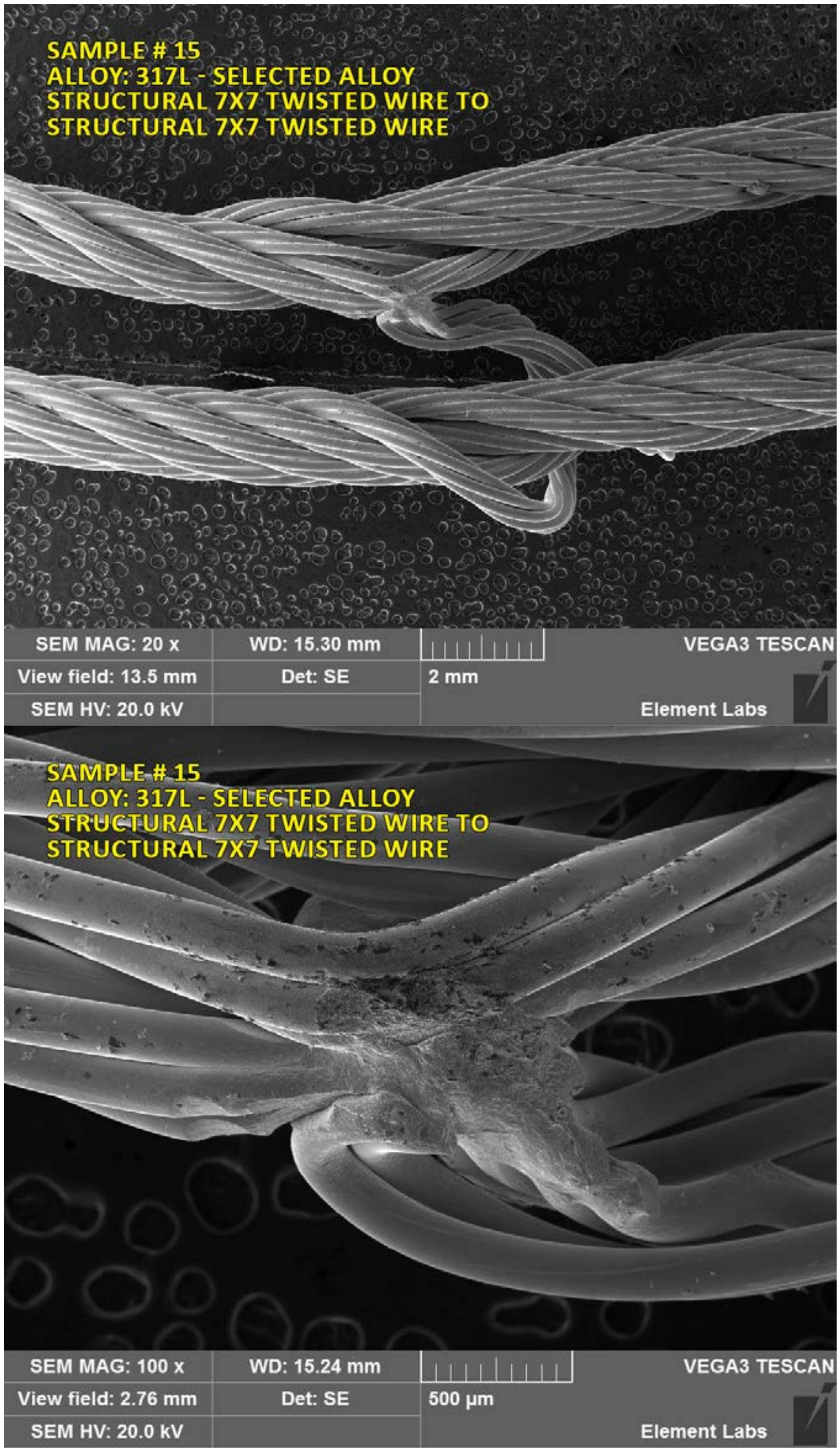


Figure 9 - SEM micrograph showing Sample #15 (alloy 317L as-welded sample, no salt fog) after mechanical strength testing. The primary break from this fracture was at the weld as shown. An attached strand is still present between the two structural wires.

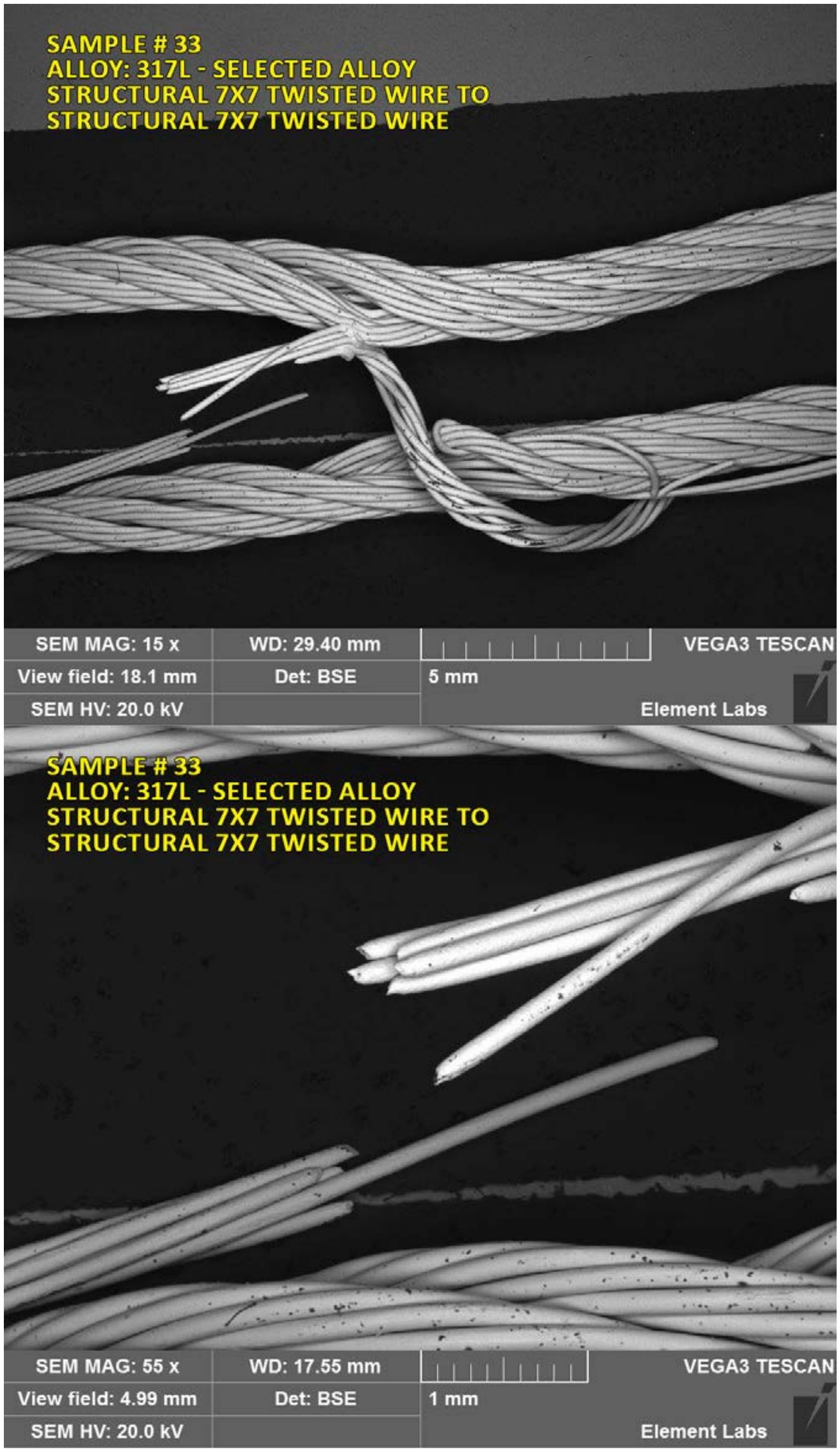


Figure 10 - SEM micrograph showing Sample #33 after salt spray testing and mechanical strength testing. Note that the majority of the breaks occurred away from the weld and that one strand is still attached between the structural members.

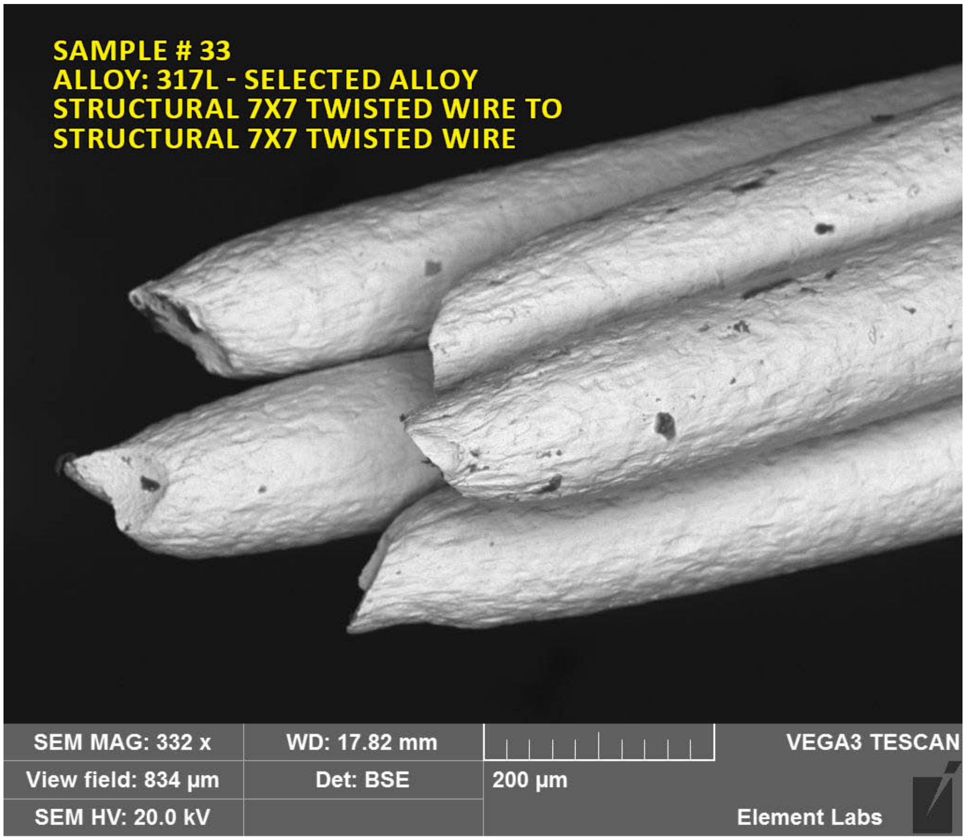


Figure 11 - SEM micrograph showing a more detailed view of the wire breaks from the previous figure. The breaks are all ductile typical of an overload failure. No evidence of pitting attack is visible on the wires or at the breaks to suggest that the 1000 hour SO_2 salt spray test degraded the twisted wire.

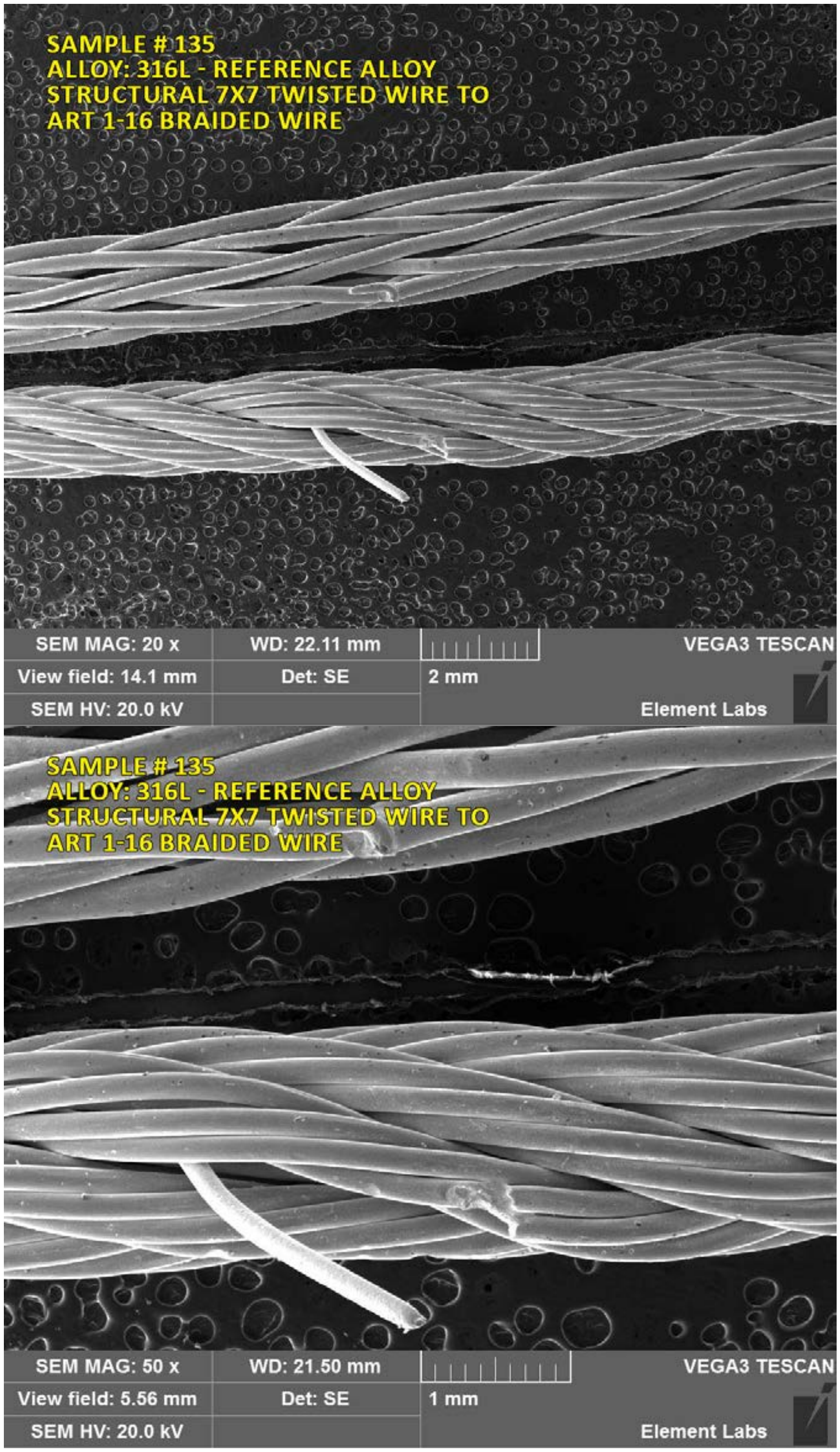


Figure 12 - SEM images showing Sample #135 after corrosion and mechanical strength testing (breaking load = 5 lbs). The measured 5 lb breaking load was due to having only one welded wire as opposed to being the result of pitting or environmental cracking.

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5.0 PANEL ASSEMBLY TESTING

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5.1. FATIGUE TEST

Included in this section:

- *Fatigue Spectrum Analysis* by RWDI dated December 9, 2013
- *Tapestry Fatigue Test Report* by Najjarine Structures dated December 31, 2013
- *Fatigue Testing - Methodology and Results* by RWDI Report # 101813

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CONSULTING ENGINEERS
& SCIENTISTS

December 9, 2013

John Bowers
Gehry Partners LLP
12541 Beatrice Street
Los Angeles, CA 90066

Re: Fatigue Spectrum Analysis
Dwight D. Eisenhower Memorial
RWDI Reference No. 1011813

Email: Johnb@foga.com

Dear John,

RWDI was retained by Gehry Partners-AECOM-JV to determine the spectrum of wind load cycles expected to act on the tapestries of the proposed Dwight D. Eisenhower Memorial in Washington, D.C. This study, which is expected to guide mock-up testing for fatigue resistance, is based upon the results of the wind tunnel studies conducted by RWDI on these tapestries (see RWDI Final Structural Wind Load Report #1011813 dated December 17, 2012) and RWDI's statistical model of the wind climate for the Washington, D.C. area (as described in the December 17, 2012 report).

By combining the time series of the pressure signal obtained from the wind tunnel tests with the wind climate model it is possible to determine a characteristic fatigue spectrum for the tapestries. This spectrum provides the number of cycles at a given wind pressure level. These are uni-directional load cycles, in that they begin at 0 psf, increase to the desired pressure, and end at 0 psf.

The spectrum presented in Figure 1 (and summarized in Table 1) is based on the pressure signal that produced the largest (in magnitude) net pressure acting on the tapestry, located within pressure zone A1 (Tables 2a, 2b, and Figure 4 from the RWDI Final Structural Wind Loading Report dated December 17, 2012 are provided herein for reference). The number of cycles are based on a design life of 100 years.

As can be seen in Table 1, based on the methodology described above, an estimated total of 682 million load cycles act on the tapestry the during the design life, with a pressure range of -10.2 psf to +40.8 psf. The overwhelming majority of these cycles are at relatively benign pressures. If only those loads within the range of 25% to 100% of the 100-year design load are considered (I.e. 0.25 x P_{100} to 1.0 x P_{100}), the number of cycles is reduced to approximately 103,000. For reference, the 0.25 x P_{100} pressure level corresponds approximately to the 20-day return period, and is therefore a very common event over the design life.

For fatigue testing, it may be practically necessary reduce the number of pressure levels and corresponding cycles that are to be considered.

Please do not hesitate to contact us if you have any further questions.

Yours very truly,

ROWAN WILLIAMS DAVIES & IRWIN Inc.

Mike Gibbons, M.E.Sc.
Project Coordinator / Wind Climate Specialist

Gregory P. Thompson, M.A.Sc.
Senior Project Manager / Associate

Scott Gamble, P.Eng.
Project Director / Principal

TABLES

TABLE 1: FATIGUE SPECTRUM

Pressure Level (psf)	Number of Cycles	Estimated Return Period
-10.2	1	
-8.5	5	
-6.8	29	
-5.1	128	
-3.4	4,777	
-1.7	269,548,351	
0	337,444,526	
1.7	59,634,698	
3.4	13,193,644	
5.1	1,780,460	
6.8	488,836	
8.5	162,051	20-day
10.2	55,712	
11.9	25,024	
13.6	12,059	
15.3	5,525	
17	2,471	
18.7	1,328	
20.4	675	
22.1	332	
23.8	169	
25.5	90	
27.2	49	
28.9	28	
30.6	16	
32.3	8	
34	4	100-year
35.7	3	In excess of 100-year return period
37.4	2	
39.1	1	
40.8	1	
Total	**682,361,003**	

Notes: The wind pressures and corresponding number of cycles beyond 34 psf represent wind load levels in excess of the 100-year design pressure, and therefore would not need to be included in the fatigue testing.

RWDI
CONSULTING ENGINEERS & SCIENTISTS

For Reference
Refer to RWDI Final Wind Load Study Report
Dated December 17, 2012

Table 2a: Recommended Wind Pressures under Normal Conditions

Tapestry Location (see Figure 4)	A		B		C		D		E		F		G	
Load Case Number	LC1a	LC1b	LC2a	LC2b	LC3a	LC3b	LC4a	LC4b	LC5a	LC5b	LC6a	LC6b	LC7a	LC7b
Pressure Zone (see Figure 4)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)
A1	**34**	**-16**	--	--	--	--	--	--	--	--	--	--	--	--
A2	**30**	**-16**	--	--	--	--	--	--	--	--	--	--	--	--
A3	**24**	**-12**	--	--	--	--	--	--	--	--	--	--	--	--
B1	--	--	**18**	**-10**	10	-6	10	-6	10	-6	10	-2	--	--
B2	--	--	**16**	**-10**	8	-4	8	-4	8	-6	8	-2	--	--
B3	--	--	**12**	**-10**	6	-4	6	-4	6	-4	6	-2	--	--
C1	--	--	8	-4	**16**	**-10**	12	-6	12	-6	12	-4	--	--
C2	--	--	6	-6	**14**	**-10**	10	-6	10	-6	10	-4	--	--
C3	--	--	6	-6	**10**	**-10**	8	-4	8	-6	8	-2	--	--
D1	--	--	4	-4	10	-4	**12**	**-10**	10	-4	10	-4	--	--
D2	--	--	6	-6	10	-4	**12**	**-10**	10	-6	10	-4	--	--
D3	--	--	6	-6	6	-4	**10**	**-10**	6	-6	6	-4	--	--
E1	--	--	6	-6	10	-4	10	-4	**12**	**-10**	10	-4	--	--
E2	--	--	4	-6	8	-4	8	-4	**10**	**-10**	8	-4	--	--
E3	--	--	6	-10	6	-2	6	-2	**10**	**-12**	6	-4	--	--
F1	--	--	6	-8	10	-4	10	-4	10	-8	**10**	**-10**	--	--
F2	--	--	4	-8	8	-2	8	-2	8	-8	**10**	**-10**	--	--
F3	--	--	6	-10	8	-2	8	-2	8	-10	**10**	**-10**	--	--
G1	--	--	--	--	--	--	--	--	--	--	--	--	**24**	**-28**
G2	--	--	--	--	--	--	--	--	--	--	--	--	**22**	**-24**
G3	--	--	--	--	--	--	--	--	--	--	--	--	**16**	**-22**

Notes:

1. The structural wind loads DO NOT contain load or safety factors and are to be applied to the structural systems in the same manner as would wind loads calculated by code analytical methods.

2. The above loads correspond to a 50-Year Basic Wind Speed of 90 mph and an Importance Factor of 1.15.

3. The wind pressures provided for each load case are to be applied to all surfaces simultaneously.

4. The wind pressures provided are to be applied normal to the front surface of each tapestry. These pressures act in the Y direction (Py); positive pressures are defined to act inwards towards the front surface, and negative pressures act outwards.

5. For each load case, the magnitude of the forces in the Y and X directions should be determined using the equations in Table 3, with positive directions defined in Figure 5. These forces should be used with the load combinations given in Table 4.

6. The provided loads are net pressures, which consider the instantaneous pressure difference across the tapestries.

7. For the wind loading on the columns, use the same pressure that is given for the adjacent tapestry. This pressure should be applied to the frontal area of the column in the appropriate direction.

8. The tributary areas associated with each pressure zone are shown in Figure 4.

9. Forces derived from the use of Table 3, are based on the solid area in each pressure zone (Figure 4). The pressures provided are approximately based on solidity ratios as depicted in Figure 4. RWDI should be contacted to review the impact on these recommendations if significant revisions of the solidity ratios occur.

For Reference
Refer to RWDI Final Wind Load Study Report
Dated December 17, 2012

CONSULTING ENGINEERS & SCIENTISTS

Table 2b: Recommended Wind Pressures to be Combined with Ice Load

Tapestry Location (see Figure 4)	A		B		C		D		E		F		G	
Load Case Number	LC1a	LC1b	LC2a	LC2b	LC3a	LC3b	LC4a	LC4b	LC5a	LC5b	LC6a	LC6b	LC7a	LC7b
Pressure Zone (see Figure 4)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)	Pos. (psf)	Neg. (psf)
A1	**21**	**-9**	--	--	--	--	--	--	--	--	--	--	--	--
A2	**18**	**-8**	--	--	--	--	--	--	--	--	--	--	--	--
A3	**17**	**-7**	--	--	--	--	--	--	--	--	--	--	--	--
B1	--	--	**11**	**-6**	6	-4	6	-4	6	-4	6	-1	--	--
B2	--	--	**10**	**-6**	7	-4	7	-4	7	-4	7	-1	--	--
B3	--	--	**11**	**-6**	7	-4	7	-4	7	-5	7	-1	--	--
C1	--	--	6	-3	**10**	**-6**	8	-4	8	-4	8	-2	--	--
C2	--	--	6	-4	**10**	**-6**	8	-4	8	-4	8	-2	--	--
C3	--	--	7	-5	**11**	**-6**	9	-5	9	-5	9	-2	--	--
D1	--	--	3	-3	7	-3	**8**	**-6**	7	-3	7	-2	--	--
D2	--	--	5	-4	8	-3	**9**	**-6**	8	-4	8	-2	--	--
D3	--	--	6	-5	9	-4	**11**	**-6**	9	-5	9	-2	--	--
E1	--	--	4	-3	7	-3	7	-3	**8**	**-6**	7	-2	--	--
E2	--	--	4	-3	7	-2	7	-2	**8**	**-6**	7	-2	--	--
E3	--	--	5	-4	8	-2	8	-2	**9**	**-6**	8	-2	--	--
F1	--	--	4	-5	7	-3	7	-3	7	-5	**7**	**-6**	--	--
F2	--	--	4	-5	7	-2	7	-2	7	-5	**8**	**-6**	--	--
F3	--	--	5	-6	8	-2	8	-2	8	-6	**11**	**-7**	--	--
G1	--	--	--	--	--	--	--	--	--	--	--	--	**15**	**-16**
G2	--	--	--	--	--	--	--	--	--	--	--	--	**13**	**-13**
G3	--	--	--	--	--	--	--	--	--	--	--	--	**12**	**-12**

Notes:

1. The structural wind loads DO NOT contain load or safety factors and are to be applied to the structural systems in the same manner as would wind loads calculated by code analytical methods.

2. The above loads correspond to a 50-Year Basic Wind Speed of 75 mph and an Importance Factor of 1.0.

3. The wind pressures provided for each load case are to be applied to all surfaces simultaneously.

4. The wind pressures provided are to be applied normal to the front surface of each tapestry. These pressures act in the Y direction (Py); positive pressures are defined to act inwards towards the front surface, and negative pressures act outwards.

5. For each load case, the magnitude of the forces in the Y and X directions should be determined using the equations in Table 3, with positive directions defined in Figure 5. These forces should be used with the load combinations given in Table 4.

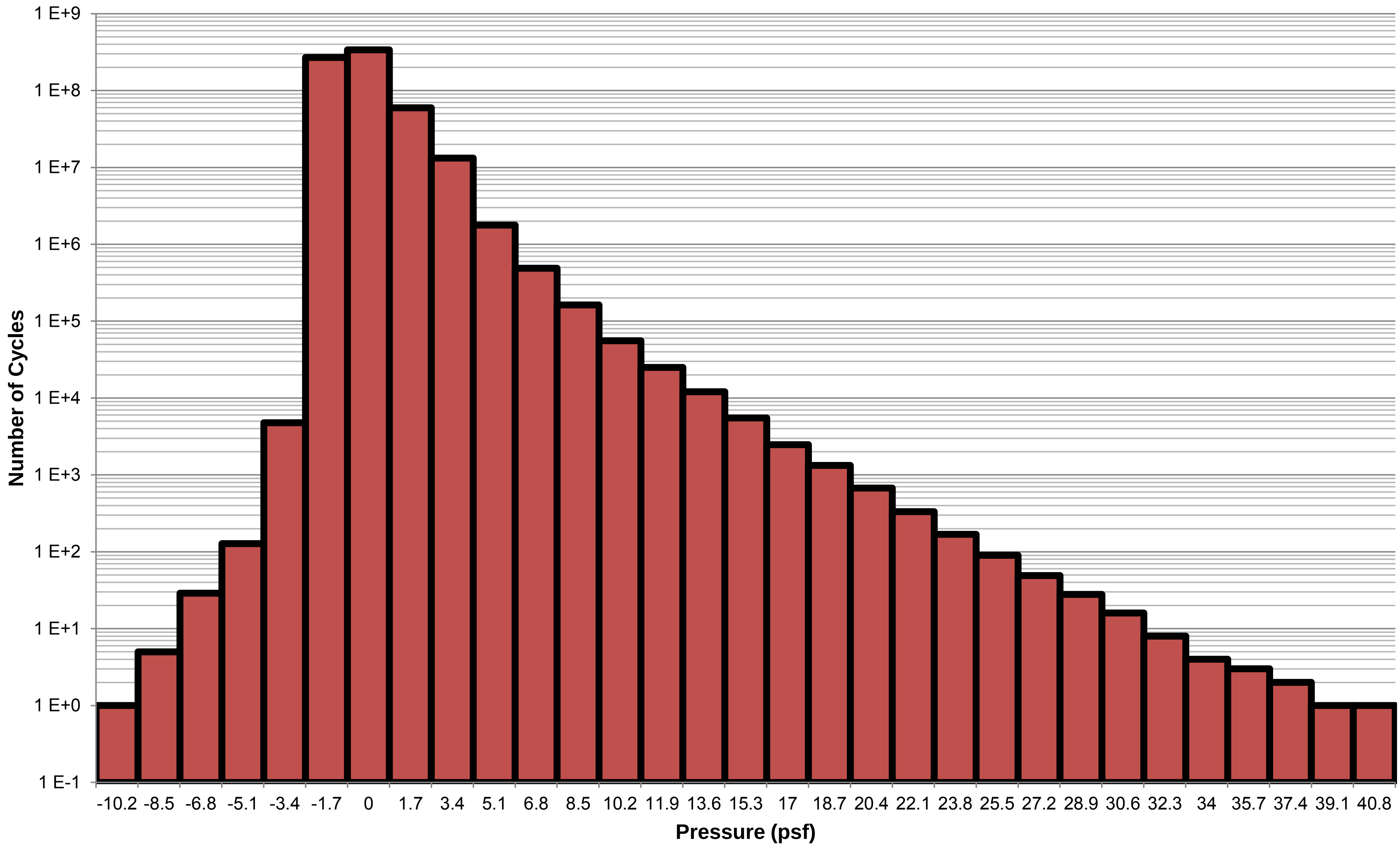
6. The provided loads are net pressures, which consider the instantaneous pressure difference across the tapestries.

7. For the wind loading on the columns, use the same pressure that is given for the adjacent tapestry. This pressure should be applied to the frontal area of the column in the appropriate direction.

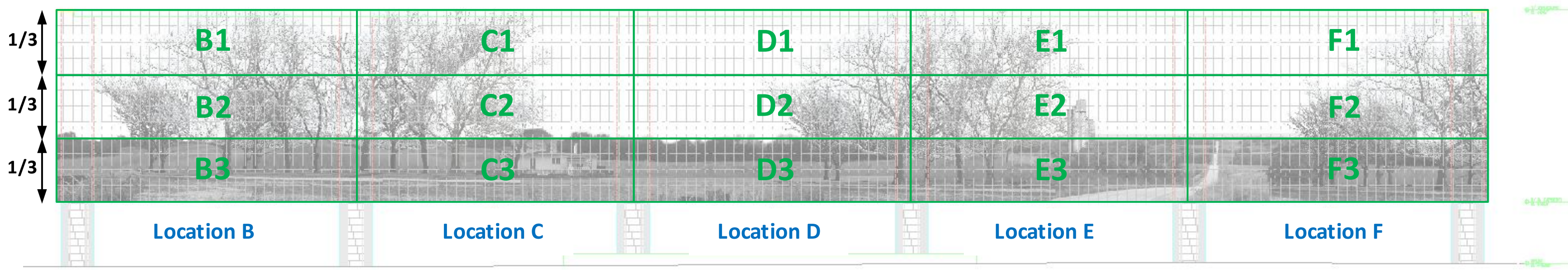
8. The tributary areas associated with each pressure zone are shown in Figure 4.

9. Forces derived from the use of Table 3 are based on the solid area, including ice coverage, in each pressure zone (Figure 4). The pressures provided are approximately based on solidity ratios as depicted in Figure 4. RWDI should be contacted to review the impact on these recommendations if significant revisions of the solidity ratios occur.

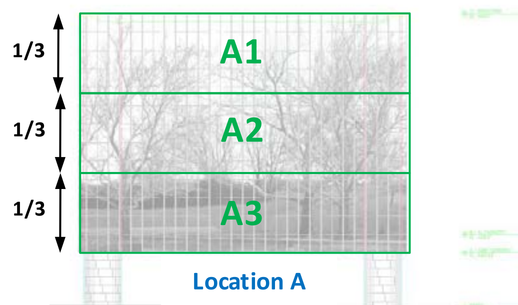
FIGURES



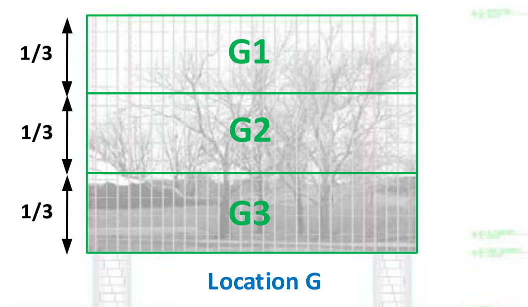
Fatigue Spectrum		Figure No. 1
Dwight D. Eisenhower Memorial – Washington, D.C.	Project #1011813	November 19, 2013



South Tapestry (North Elevation)



East Tapestry (West Elevation)



West Tapestry (East Elevation)

Key Plan of Pressure Zones		Figure No. 4
Dwight D. Eisenhower Memorial – Washington, DC	Project #1011813	Date: May 7, 2012

RWDI

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TAPESTRY FATIGUE TEST REPORT

Date: **12/31/2013**

Job Number: **12811**

Project: **Eisenhower Memorial**

Address: **Washington, DC**

Revisions:

Date:

Sheets:

The enclosed structural calculations are for the tapestry wall system and its anchorages related to the abovementioned project.

Structural analysis and design of other non-structural elements and their attachment are the responsibility of others.

The enclosed structural calculations are intended for use only for the specific project specified above, and intended for use by experienced and qualified professionals.

Structural stamp & wet signature

TABLE OF CONTENTS

1 GENERAL FATIGUE DESCRIPTION

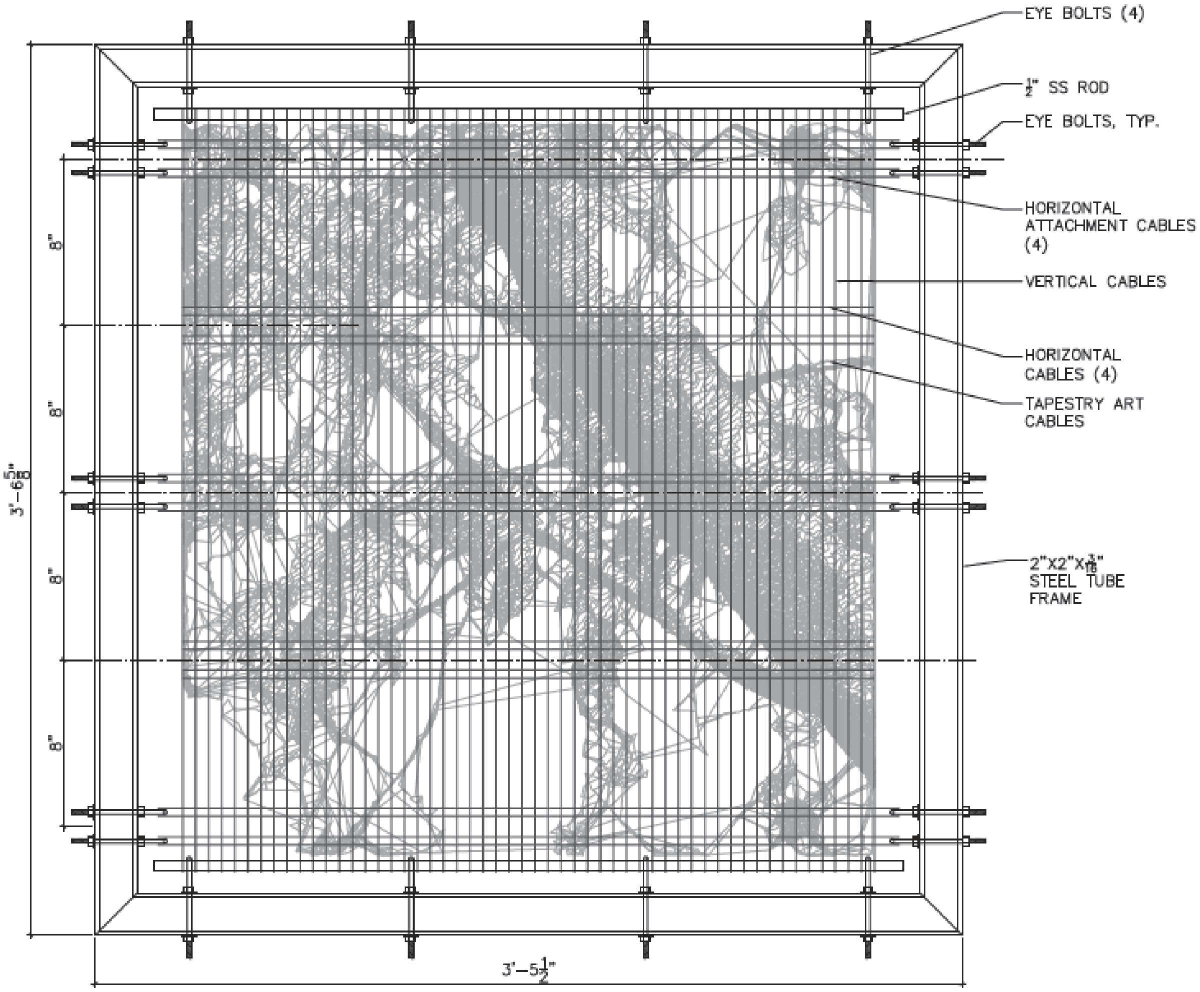
All structures and mechanical components that are cyclically loaded can fail by fatigue. With limited input data, constant amplitude fatigue analysis is used to make a simple and quick estimate of the likely fatigue performance or durability.

For the purpose of testing the subject tapestry sample shown in section 2, we are using variable amplitude or spectrum loads using RWDI's Fatigue Spectrum Analysis based on the results of the wind tunnel studies conducted on the tapestries and the statistical model of the wind climate for the Washington, D.C. area.

The number of cycles which will be used is also based on the total number of cycles per 100-year period for different stress amplitudes.

2 FATIGUE TESTING PARAMETERS

Fatigue test sample



Fatigue test pressures & number of cycles

Per RWDI's Fatigue Spectrum Analysis based on the results of the wind tunnel studies conducted on the tapestries and the statistical model of the wind climate for the Washington, D.C. area (refer to attached Fatigue Spectrum Analysis report done by RWDI, Reference No. 1011813), we propose the application of a range of pressures with corresponding number of cycles, the maximum testing pressure shall be 34 PSF, which represents maximum pressure per 100-year period per RWDI Fatigue Spectrum Analysis Table 1, and the minimum testing pressure will be 10.2 PSF, which represents 30% of maximum pressure per 100-year period per RWDI Fatigue Spectrum Analysis Table 1.

The range of pressures shall be cycled as per the table shown below and shall be applied to actual sample surface or adjusted to account for open area within sample.

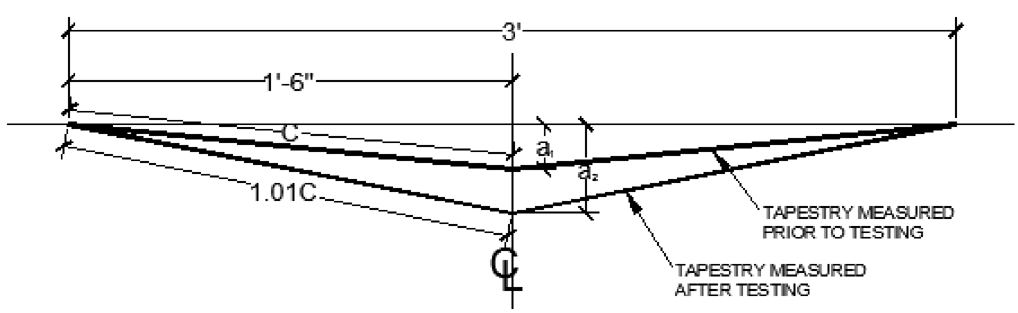
The total number of cycles shall be 103,490 cycles which represents the total number of cycles per 100-year period for wind pressures between 10.2 and 34 PSF.

Pressure Level (psf)	Number of Cycles	Estimated Return Period
10.2	55,712	
11.9	25,024	
13.6	12,059	
15.3	5,525	
17	2,471	
18.7	1,328	
20.4	675	
22.1	332	
23.8	169	
25.5	90	
27.2	49	
28.9	28	
30.6	16	
32.3	8	
34	4	100-year
	TOTAL=103,490	

PASS/FAIL CRITERIA

A. Permanent Deformation

Horizontal wires (assembled) increase in length shall not exceed 1%. (Maintaining the strain at a maximum stress of 1.2 times the yield stress). Refer to illustration below.



The fatigue tapestry sample should be placed horizontally prior to testing and the center of the tapestry sample shall be measured (in inches) at the location shown below. This measurement labeled as “a_1” will be compared to the measurement (in inches) at the same location after the completion of the test labeled “a_2”.

$$C := \sqrt{a_1^2 + 18^2}$$

$$a_2 := \sqrt{(1.01 \cdot C)^2 - (18)^2}$$

$$a_2 := \sqrt{(1.02) \cdot \left(\sqrt{a_1^2 + 18^2}\right)^2 - (18)^2}$$

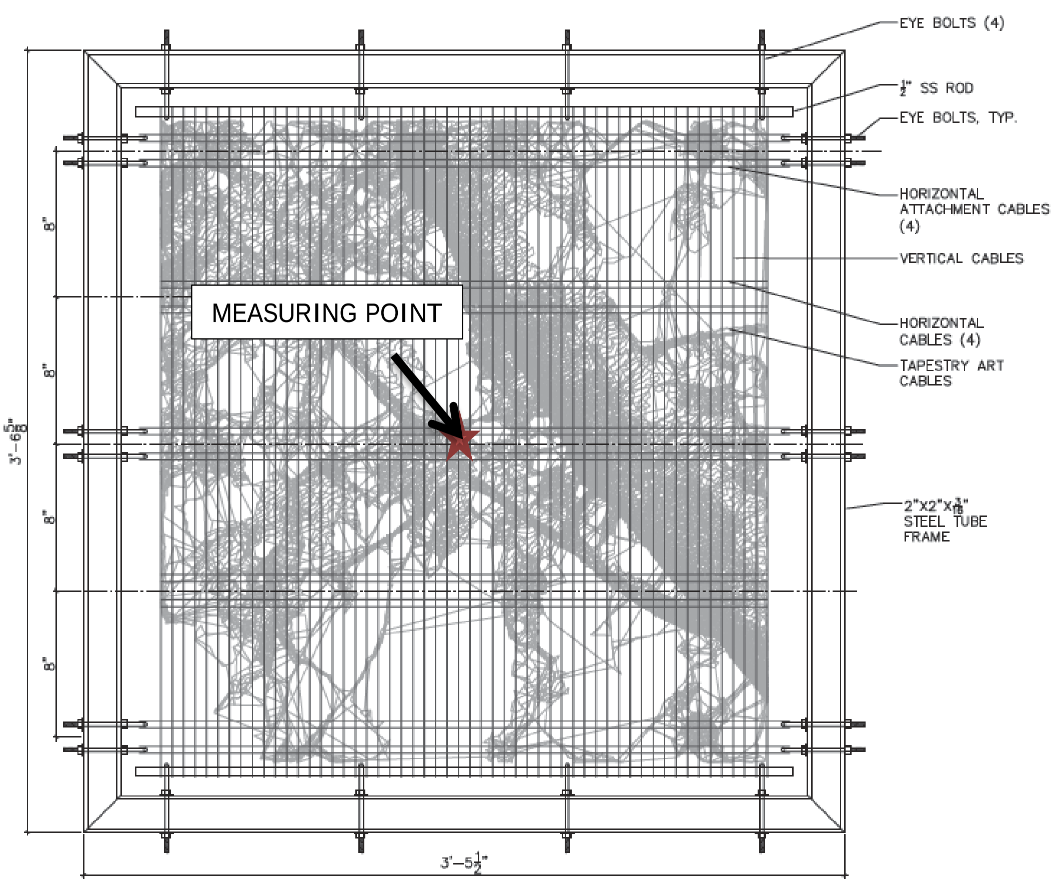
$$a_2 := \sqrt{(1.02) \cdot \left(a_1^2 + 18^2\right) - (18)^2}$$

$$a_2 := \sqrt{(1.02) \cdot \left(a_1^2\right) + 0.02 \cdot (18)^2}$$

$$a_2 := \sqrt{1.02 \cdot a_1^2 + 6.48}$$

The measurement “a_2” shall not exceed the following

$$\sqrt{1.02 \cdot a_1^2 + 6.48}$$



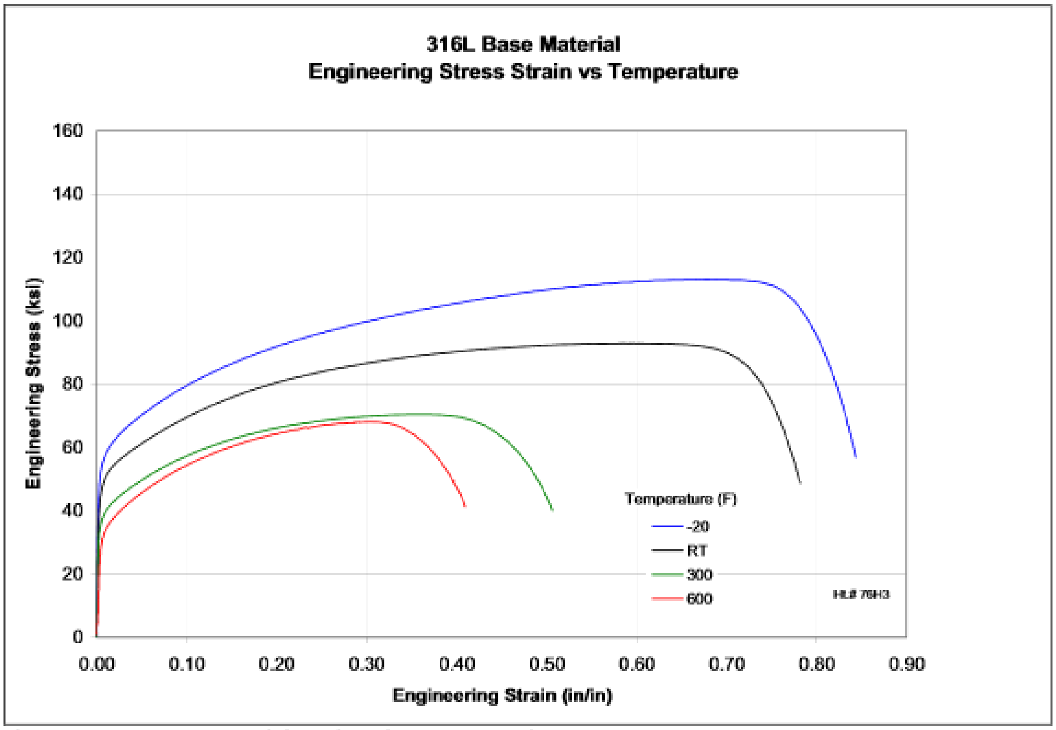


Figure 6. 316L Base Material Engineering Stress-Strain

B. <u>Welded Joints</u>

A visual inspection of the welded points shall be made before and after the completion of the test for structural and aesthetic purposes.

1. <u>Evaluation of Structural Wire weld joints</u>
   20% of the total number of weld joints between the structural horizontal and structural vertical wires is required for strength (including a safety factor of 4). A visual inspection after the fatigue test shall validate percentage of structural welds that are intact. The review of the structural welds shall be limited to those structural welds that are easily visible. Structural welds under layers of art wire are not required to be evaluated.

2. <u>Evaluation of Art Wire weld joints</u>
   An aesthetic only review will be performed. Since these cables are not structural in nature this test will be to review any formidable damage in appearance to the image displayed on the tapestry. The conclusion of this test will be to determine if the artwork has been disfigured due to any permanent deformation caused by the fatigue testing regime.

3 LOADING & STRESS DETERMINATION

Dead Loading per E.O.R..

Tapestry Weight for analysis per EOR $DL_t := 20psf$

Tapestry Ice Weight for analysis per EOR $DL_{ti} := 20.64psf$

Wind Loading per Wind Study (RWDI Project No. 1011813), with Porosity Study incorporated (max.)

Wind Loads-Typical Condition
Upper third surface $W_u := 25psf$

Wind Loads-Typical Condition
Middle third surface $W_m := 15psf$

Wind Loads-Typical Condition
Lower third surface $W_l := 10psf$

Wind Loading per Wind Study (RWDI Project No. 1011813), 90 mph, Iw=1.15

Wind Loads-Typical Condition
Upper third surface $W_{in\_u} := 34psf$ $W_{out\_u} := -16psf$

$W_u := W_{in\_u} - W_{out\_u}$ $W_u = 50 \cdot psf$

Wind Loads-Typical Condition
Middle third surface $W_{in\_m} := 30psf$ $W_{out\_m} := -16psf$

$W_m := W_{in\_m} - W_{out\_m}$ $W_m = 46 \cdot psf$

Wind Loads-Typical Condition
Lower third surface $W_{in\_l} := 24psf$ $W_{out\_l} := -12psf$

$W_l := W_{in\_l} - W_{out\_l}$ $W_l = 36 \cdot psf$

Wind Ice Loading per Wind Study (RWDI Project No. 1011813), 75mph, Iw=1.0

Wind Loads-Typical Condition
Upper third surface $W_{in\_u} := 21psf$ $W_{out\_u} := -9psf$

$W_{ui} := W_{in\_u} - W_{out\_u}$ $W_{ui} = 30 \cdot psf$

Wind Loads-Typical Condition
Middle third surface $W_{in\_m} := 18psf$ $W_{out\_m} := -8psf$

$W_{mi} := W_{in\_m} - W_{out\_m}$ $W_{mi} = 26 \cdot psf$

Wind Loads-Typical Condition
Lower third surface $W_{in\_l} := 17psf$ $W_{out\_l} := -7psf$

$W_{li} := W_{in\_l} - W_{out\_l}$ $W_{li} = 24 \cdot psf$

<u>Seismic Loading per chapter 15, ASCE 7-05.</u>

Component response modification factor $R := 3.5$ $\quad C_d := 3$ $\quad \pi_o := 1.75$ $\quad$ Table 15.4-2

Importance factor, Type II $\quad I_p := 1.0$

Spectral acceleration $\quad S_{DS} := 0.163$

Operating weight of panel $\quad W_p := 20 \cdot psf$

Seismic coefficients $\quad C_s := \dfrac{S_{DS}}{\left(\dfrac{R}{I_p}\right)}$ $\quad C_s = 0.0466$

$C_{s\_min} := 0.044 \cdot S_{DS} \cdot I_p$ $\quad C_{s\_min} = 0.007$

Horizontal seismic design force $\quad Fp_{h1} := C_s \cdot W_p$

$\boxed{Fp_{h1} = 0.93 \cdot psf}$

<u>Thermal Expansion of horizontal wire considered within one panel</u>

Length of horizontal $\quad L_h := 36in$

Length of vertical (2 spans) $\quad L_v := 24in$

Area of wire $\quad A_w := \dfrac{\pi}{4} \cdot \left(\dfrac{1}{16} in\right)^2$ $\quad A_w = 0.0030679616 \cdot in^2$

Inertia of wire $\quad I_w := \dfrac{\pi}{64} \cdot \left(\dfrac{1}{16} in\right)^4$ $\quad I_w = 0.0000007490 \cdot in^4$

Coefficient of thermal expansion per deg. F for 100 degrees $\quad CTE := 0.00099$

Total Temperature range, deg. F $\quad \Delta_t := 120$

Temperature mean change , deg. F $\quad \Delta_{tm} := 60$

Change in length in horizontal wire $\quad \Delta_{ex} := \dfrac{CTE \cdot \Delta_{tm} \cdot L_h}{100}$ $\quad \Delta_{ex} = 0.021 \cdot in$ $\quad \Delta_{ex} = 0.54 \cdot mm$

Change in stress in horizontal wire $\quad \zeta := \dfrac{E_{ss} \cdot CTE \cdot \Delta_{tm}}{100}$ $\quad \zeta = 16.632 \cdot ksi$

Tension Force on horizontal wire as a result of the change in length

$T_{\Delta.h} := \zeta \cdot A_w$ $\quad \boxed{T_{\Delta.h} = 51 \cdot lbf}$

Force on vertical wire and shear on weld as a result of the change in length of horizontal wire

$V_{\Delta.w} := \dfrac{48 \cdot \Delta_{ex} \cdot E_{ss} \cdot I_w}{L_v^3}$ $\quad \boxed{V_{\Delta.w} = 0.0016 \cdot lbf}$ $\quad$ Negligable

Determine Tension Loading on vertical 1/16" 316L annealed cables at 5/8" O.C.

Note: 316L material and stress properties are used in the analysis due to availability of such properties, properties of 317L Stainless Steel are equivalent.

Tapestry panel Height, typ.	$H_{tp} := 15ft$		
Tapestry panel width, typ.	$b_t := 3ft$		
Dia. of individual panel horizontal and vertical wire, typ.	$d_{ipw} := \frac{1}{16}in$		
Yeild stress, 316L Stainless Steel.	$F_y := 42ksi$		
Ult. Tensile stress, 316L Stainless Steel.	$F_{ut} := 98.6ksi$	$F_{ut} = 680 \cdot MPa$	
Elasticity stress, 316L Stainless Steel.	$E_{ss} := 28000ksi$	$E_{ss} = 193053 \cdot MPa$	
Allowable tension stress per wire-DL	$F_{a\_dl} := \min(0.45 \cdot F_y, 0.5 \cdot F_{ut})$		$F_{a\_dl} = 19 \cdot ksi$
Allowable tension stress per wire-WL	$F_{a\_wl} := 1.6 \cdot \min(0.45 \cdot F_y, 0.5 \cdot F_{ut})$		$F_{a\_wl} = 30 \cdot ksi$
Tapestry Weight for analysis per EOR	$DL := 20psf$		
Tapestry Ice Weight for analysis per EOR	$DL_i := 20.64psf$		
Tributary Width & Typical Span	$tw_1 := \frac{5}{8}in$	$L := 16in$	

Load combinations per ASCE/SEI 7-05 (ASD):

D	5.	$D + W$
$D + D_i$	6.	$D + 0.75 \cdot W$
$D + 0.7 \cdot D_i + 0.7 \cdot W$	7.	$0.6 \cdot D + 0.7 \cdot D_i + 0.7 \cdot W$

Vertical uniform loading (one span between horizontals):

$\omega_d := (DL) \cdot (tw_1)$ $\qquad \omega_d = 0.0868 \cdot \frac{lbf}{in}$

$\omega_{di} := (DL_i) \cdot (tw_1)$ $\qquad \omega_{di} = 0.0896 \cdot \frac{lbf}{in}$

Vertical reaction at each weld to double horizontal cables:

$P_{DL\_V} := \frac{1}{2} \cdot (DL + DL_i) \cdot (tw_1) \cdot (L)$ $\qquad \boxed{P_{DL\_V} = 1.4111 \cdot lbf}$

Cumalative Vertical loading (tension):

$P_{TDL\_V} := (DL + DL_i) \cdot (tw_1) \cdot (H_{tp})$ $\qquad \boxed{P_{TDL\_V} = 31.7500 \cdot lbf}$

Allowable tension force per verical wire $\qquad T_{all.v} := (F_{a\_dl}) \cdot (A_w)$

$\boxed{T_{all.v} = 58 \cdot lbf} \quad > \quad P_{TDL\_V} = 32 \cdot lbf$ OK

Determine Tension Loading on horizontal 1/16" 316L annealed cables at 16" O.C.

Tapestry Weight for analysis per EOR $DL := 20psf$

Tapestry Ice Weight for analysis per EOR $DL_i := 20.64psf$

Wind Load $W_{in\_u} := 34psf$ $W_{out\_u} := -16psf$

$W_u := W_{in\_u} - W_{out\_u}$ $W_u = 50 \cdot psf$

Tributary Width & Typical Span $tw_2 := 16in$ $L := 3ft$

Horizontal uniform loading-out of plane (one span):

$\omega_w := (W_u) \cdot (tw_2)$ $\omega_w = 5.5556 \cdot \dfrac{lbf}{in}$ or

$\omega_{wp} := \omega_w \cdot \left(\dfrac{5}{8} in\right)$ $\omega_{wp} = 3 \cdot lbf$ at 5/8" O.C.

Tension on each horizontal wire per attached (14% sag):

$T_{w.h} := \dfrac{151.12lbf}{4} \cdot \left(\dfrac{16in}{12in}\right)$ $\boxed{T_{w.h} = 50 \cdot lbf}$

Shear on each weld to vertical wire:

$P_{v.w} := \dfrac{T_{w.h}}{\dfrac{(L)}{tw_1}}$ $\boxed{P_{v.w} = 0.87 \cdot lbf}$

Allowable tension force per horizontal wire $T_{all.v} := (F_{a\_wl}) \cdot (A_w)$

$\boxed{T_{all.v} = 93 \cdot lbf}$ > $T_{w.h} = 50 \cdot lbf$ OK

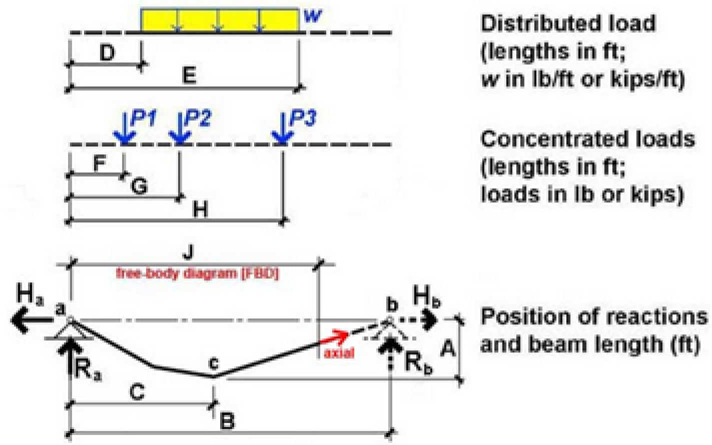


Fig. 1. *Cable geometry (lengths) and magnitude of loads*

Update

Positions of loads and reactions (ft)								
Sag	Span	Sag point	Uniform load position		Point load positions			FBD
A	B	C	D	E	F	G	H	J
0.42	3	1.5	0	3	1	1.25	1.5	0.1
Loads (use kips/ft and kips or lb/ft and lb)								
			w		P1	P2	P3	
			50		0	0	0	

Vert reaction at "a"	Vert reaction at "b"	Horiz reaction at "a,b"	Axial force(s) at FBD	FBD Height
75	75	133.93	151.12	0.05

Weld Capacity for Structural 7x7 Twisted Wires per calculation and testing

Tensile strength of E316L-16 electrode	$Fu_{E316} := 98ksi$	$Fu_{E316} = 676 \cdot MPa$
Yeild stress, 316L Stainless Steel.	$F_y := 42ksi$	$F_y = 290 \cdot MPa$

Allowable weld @ 20% total contact

$$F_a := 0.30 \cdot F_{ut} \cdot \left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right) \cdot (20\%) \qquad F_a = 16.49 \cdot lbf$$

Allowable shear of base metal @ 20% total contact

$$F_v := 0.40 \cdot F_y \cdot \left[\left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right)\right] \cdot (20\%) \qquad F_v = 13.13 \cdot lbf$$

Ultimate weld @ 20% total contact

$$F_{au} := F_{ut} \cdot \left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right) \cdot (20\%) \qquad F_{au} = 54.96 \cdot lbf$$

Ultimate shear of base metal @ 20% total contact

$$F_{vu} := F_y \cdot \left[\left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right)\right] \cdot (20\%) \qquad F_{vu} = 32.81 \cdot lbf$$

Allowable Weld Capacity	$V_{all\_s} := \min(F_a, F_v)$	$V_{all\_s} = 13.125 \cdot lbf$
Allowable Weld Capacity (Single to Double 7x7 Twisted)	$V_{all\_d} := \min(2 \cdot F_a, 2 \cdot F_v)$	$V_{all\_d} = 26.250 \cdot lbf$
Ultimate Weld Capacity	$V_{alt\_s} := \min(F_{au}, F_{vu})$	$V_{alt\_s} = 32.813 \cdot lbf$
Ultimate Weld Capacity (Single to Double 7x7 Twisted)	$V_{alt\_d} := \min(2 \cdot F_{au}, 2 \cdot F_{vu})$	$V_{alt\_d} = 65.625 \cdot lbf$
Average Tested Weld Capacity - (Structural Torque shear Test)	$V_{ult\_test1} := 36.4lbf$	(2B Joint Type 1, 316L)
Average Tested Weld Capacity - (Structural Peel Test)	$V_{ult\_test2} := 42.2lbf$	(2B Joint Type 1, 316L)

Allowable Weld Capacity from Testing with factor of safety of 4

$$V_{all\_test} := \min\left(\frac{1}{4} \cdot V_{ult\_test1}, \frac{1}{4} \cdot V_{ult\_test2}\right)$$

$$V_{all\_test} = 9.100 \cdot lbf \quad > \quad P_{Res.w} := \sqrt{(P_{DL\_V})^2 + (P_{v.w})^2} \qquad P_{Res.w} = 1.66 \cdot lbf \qquad \text{OK}$$

Weld Capacity for Art Braided Wires per calculation and testing

Average spacing of Art welds in any direction $l_{aw} := 1in$

Tensile strength of E316L-16 electrode $Fu_{E316} := 98ksi$ $Fu_{E316} = 676 \cdot MPa$

Yeild stress, 316L Stainless Steel. $F_y := 42ksi$ $F_y = 290 \cdot MPa$

Shear per art weld (maximum): $P_{d.aw} := (DL + DL_i) \cdot (l_{aw}) \cdot (l_{aw})$ $P_{d.aw} = 0.2822 \cdot lbf$

Tension per art weld (maximum): $P_{w.aw} := (W_{in\_u}) \cdot (l_{aw}) \cdot (l_{aw})$ $P_{w.aw} = 0.2361 \cdot lbf$

Allowable weld @ 20% total contact

$F_a := 0.30 \cdot F_{ut} \cdot \left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right) \cdot (20\%)$ $F_a = 16.49 \cdot lbf$

Allowable shear of base metal @ 20% total contact

$F_v := 0.40 \cdot F_y \cdot \left[\left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right)\right] \cdot (20\%)$ $F_v = 13.13 \cdot lbf$

Ultimate weld @ 20% total contact

$F_{au} := F_{ut} \cdot \left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right) \cdot (20\%)$ $F_a = 16.49 \cdot lbf$

Ultimate shear of base metal @ 20% total contact

$F_{vu} := F_y \cdot \left[\left(\frac{1}{16} in\right) \cdot \left(\frac{1}{16} in\right)\right] \cdot (20\%)$ $F_v = 13.13 \cdot lbf$

Allowable Weld Capacity $V_{all\_s} := \min(F_a, F_v)$ $V_{all\_s} = 13.125 \cdot lbf$

Ultimate Weld Capacity $V_{alt\_s} := \min(F_{au}, F_{vu})$ $V_{alt\_s} = 32.813 \cdot lbf$

Average Tested Weld Capacity - (Art Torque shear Test) $V_{ult\_test1} := 12.4lbf$ (3B Joint Type 2, 316L)

Average Tested Weld Capacity - (Art Peel Test) $V_{ult\_test2} := 11.8lbf$ (3B Joint Type 2, 316L)

Allowable Weld Capacity from Testing with factor of safety of 4 $V_{all\_test} := \min\left(\frac{1}{4} \cdot V_{ult\_test1}, \frac{1}{4} \cdot V_{ult\_test2}\right)$

$V_{all\_test} = 2.950 \cdot lbf$ > $V_{Res.w} := \sqrt{(P_{d.aw})^2 + (P_{w.aw})^2}$ $V_{Res.w} = 0.37 \cdot lbf$ OK

RWDI
CONSULTING ENGINEERS & SCIENTISTS

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N1K 1B8

February 4, 2014

John Bowers
Gehry Partners LLP
12541 Beatrice Street
Los Angeles, CA 90066

Email: johnb@foga.com

Re: Fatigue Testing – Methodology and Results Report
Dwight D. Eisenhower Memorial
RWDI Reference No. 1011813

Dear John,

Rowan Williams Davies & Irwin Inc. (RWDI) was commissioned to perform fatigue testing on a tapestry sample from the Dwight D. Eisenhower Memorial in Washington, DC. The purpose of this testing was to determine the impact of repeated high pressure cycles applied to the tapestry.

Test Details

The intent of the fatigue testing was to simulate wind-induced load cycles expected to act on the tapestry during moderate to extreme wind events. Pressure levels ranging from the approximately 1-month return period event to the 100-year return period event were considered. Common low wind events (i.e. those that occur frequently (a recurrence interval of less than 1-month) were **not** represented in the current testing. Other types of environmental loading other than wind, such as rain, snow, icing or thermal loads were **not** considered in this testing.

RWDI previously conducted a fatigue spectrum analysis for the Dwight D. Eisenhower Memorial Tapestries, which was summarized in the Fatigue Spectrum Analysis report provided by RWDI, dated December 9, 2013. The magnitude and number of wind pressure cycles was selected by the project team based on RWDI's December 9, 2013 report, as documented in the Tapestry Fatigue Test Report from Najjarine Structures dated December 31, 2013.

To conduct the fatigue testing, a roughly 3.5 ft by 3.5 ft tapestry sample has been provided to RWDI by the design team.

The pressure levels tested by RWDI have been summarized in Table 1. The target number of pressure levels (from Najjarine Structures December 31, 2013 Report) and the associated wind speeds (3-second gust, in open terrain at 33 ft) are also provided.

Table 1: Pressure levels and associated number of cycles to be tested in pressure chamber

Level	Design Pressure Level, P_{Design} (psf)	Associated Wind Speed (mph, 3-second gust at 33 ft in open terrain)	Test Chamber Internal Pressure Level, $P_{Internal}$ (psf)	Number of Cycles (Target)	Number of Cycles (Tested)
1	10.2	53	6.4	55,712	18,967
2	11.9	57	7.4	25,024	34,688
3	13.6	61	8.5	12,059	26,410
4	15.3	64	9.5	5,525	13,391
5	17	68	10.6	2,471	3,855
6	18.7	71	11.6	1,328	2,421
7	20.4	74	12.7	675	1,613
8	22.1	77	13.8	332	1,873
9	23.8	80	14.8	169	853
10	25.5	83	15.9	90	689
11	27.2	86	16.9	49	172
12	28.9	89	18.0	28	133
13	30.6	91	19.1	16	72
14	32.3	94	20.1	8	45
15	34	96	21.2	4	65
Total	**--**	**--**	**--**	**103,490**	**104,384**

From Table 1, it is evident that the number of targeted cycles is different than the final number of tested cycles. The total number of tested cycles exceeds the total number of cycles targeted for study. With the shift in the tested cycles from lower pressure levels (largely the first pressure level) to higher pressure levels, it can be concluded that this shift resulted in additional high pressure level cycles being applied to the tapestry sample, and was therefore conservative. It can be concluded that the spectrum of tested cycles was more onerous than the test plan called for, as lower stress cycles were replaced with higher stress cycles.

An important consideration in the application of pressure on the tapestry sample was to ensure that the pressures within the test chamber, $P_{Internal}$, resulted in the same amount of wind load as would be caused by the design level pressures, P_{Design}. The P_{Design} values are based on the previous studies completed by RWDI on the structural wind loading of the tapestry structure, which are described in RWDI's Structural Wind Load Report, dated December 12, 2012 and the December 9, 2013 fatigue report. These P_{Design} values take into account the porosity and drag effects of the tapestry, such that the intended design level force exerted wind, F_{Wind}, relates to P_{Design} according to:

$$P_{Design} = \frac{F_{Wind}}{A_{Tapestry,Solid}} \quad (1)$$

The relationship between $P_{Internal}$ and P_{Design} has been calculated to ensure that the force exerted by the pressure chamber onto the tapestry, F_{PC}, is equivalent to F_{Wind}. F_{PC} is calculated as:

$$P_{Internal} = \frac{F_{PC}}{A_{Tapestry,Total}} \quad (2)$$

Setting F_{PC} equal to F_{Wind} and rearranging Equations (1) and (2) yields the following relationship between $P_{Internal}$ and P_{Design}:

$$P_{Internal} = P_{Design} \times \frac{A_{Tapestry,Solid}}{A_{Tapestry,Total}} \quad (3)$$

Image processing was used to determine the ratio between $A_{Tapestry,Solid}$ and $A_{Tapestry,Total}$, and was calculated to be 0.62. This ratio was determined based on the images of the Tapestry Sample shown in Figure 1.

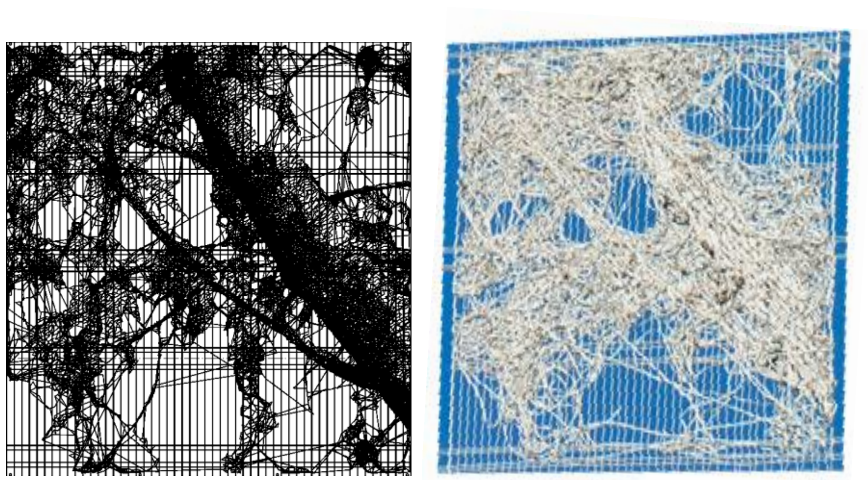


Figure 1: Images used to calculate solidity ratio of test sample; CAD drawing of tapestry sample (left) and picture taken of tapestry sample (right)

The tapestry sample was placed in a pressure chamber which is capable of generating fluctuating pressures within the desired range of $P_{Internal}$ values listed in Table 1. The pressure chamber is shown in Figure 2. The fan draws air through the pressure chamber and when the flow valve is shut, creates a negative pressure within the pressure chamber. The flow valve which is actuated by a variable speed drive rotates and creates a fluctuating pressure within the pressure chamber at a frequency of approximately 1 Hz.

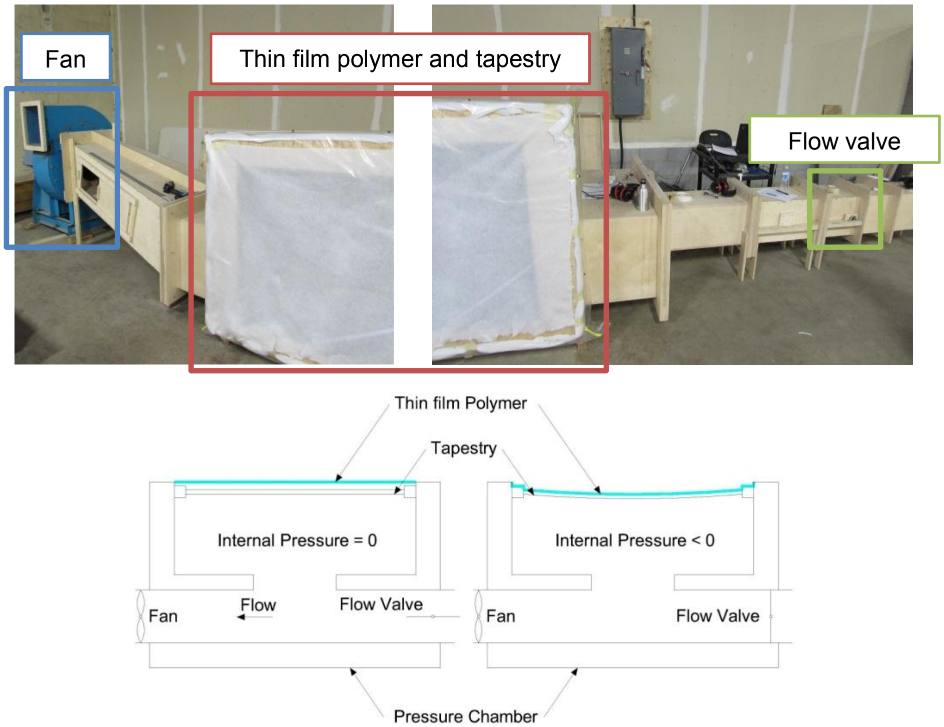


Figure 2: Pressure Chamber; pre-test photos (top) and schematic (bottom)

A thin-film polymer was used to transfer the internal pressure acting within in pressure chamber to the tapestry. To minimize the likelihood of punctures to the thin-film polymer, a perforated thin-film polymer and batting breather layer were loosely laid between the thin-film polymer and the tapestry sample. This setup is shown in Figure 3. This setup is similar to that used by the composites industry in the vacuuming bagging process. For clarity, the measurement point for the laser transducer is indicated in red in the far left and middle left images of Figure 3.

Figure 3: The tapestry sample installed in the pressure chamber. The uncovered tapestry (far left) is covered by three layers; a perforated thin film polymer layer (middle left) and batting breather layer (middle right) are used to minimize the likelihood of the tapestry causing punctures in the thin-film polymer layer (far right).

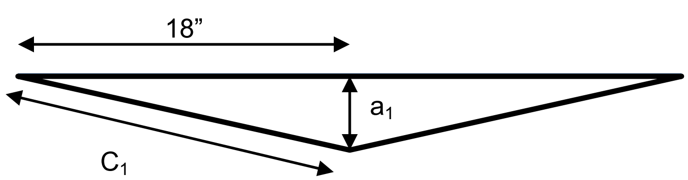
The pressure chamber was instrumented with a pressure transducer capable of measuring the instantaneous difference between the pressure within the chamber and the ambient room pressure. A laser transducer was used to measure the deflections of the tapestry sample during testing; the measurement point is slightly above the middle of the tapestry sample and is indicated in red in Figure 3.

The signals of the pressure transducer and laser transducer were recorded throughout testing, at a sampling frequency of 30 samples per second, and were retained for post-processing.

Test Results

Post-test, the pressure transducer signal was used to determine the number of cycles tested, and to which pressure level the cycle reached. This information was used to populate the “Number of Cycles (Tested)” column of Table 1.

Two Pass/Fail Criteria were adopted by the design team, as described in the Narjjarine Structures December 31, 2013 report. The first criterion was in regards to the permanent deformation of the horizontal wires, which are the main structural support of the tapestry. At the end of the test cycles, the permanent increase in length of the horizontal wires was not to exceed 1%. For the tapestry sample, a permanent increase in the length of the horizontal wires of 1% equates to a permanent increase in deflection (or sag) at the midpoint of the tapestry of 2.55”. This is based on setting the a_1 value to 0 in the calculation procedure on Page 6 from Najjarine Structures December 31, 2013 report, as is demonstrated Figure 4 and the equations below:

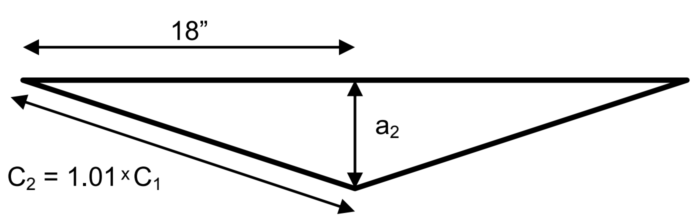


$$C_1{}^2 = a_1^2 + 18"^2 \quad (4)$$

Assuming a_1=0

$$C_1 = 18" \quad (5)$$

Figure 4a: Initial condition.



$$C_2^2 = a_2^2 + 18"^2 \quad (6)$$

C is allowed to increase by 1%, thus C_2 can be defined

$$C_2 = C \times 1.01 = 18" \times 1.01 \quad (7)$$

$$(18" \times 1.01)^2 = a_2^2 + 18"^2 \quad (8)$$

Rearranging and solving for a_2 yields

$$a_2 = 2.55” \quad (9)$$

Figure 4b: Derivation of maximum allowable deflection of the tapestry.

From the Najjarine Structures report, C_1 is defined as the hypotenuse of the triangle formed by the half-width of the sample (18”) and the initial deflection of the sample, a_1. The length C_1 is defined by Equation (4). As the tapestry was tested vertically, no initial measurement for a_1 was taken with a gravity induced sag. Therefore for purposes of evaluation of the permanent set we have conservatively taken a_1 to be 0 resulting in C_1 equaling 18”. This is a conservative approach as setting a_1 greater than 0 yields larger allowable values for a_2. In this process, C_1 is theoretically allowed to lengthen by 1%, thus C_2 has a value of 18” x 1.01 which when put into Equation (6) allows for the maximum allowable permanent deformation a_2 to be obtained.

The laser transducer was used to determine the distance between the laser and a target on the sample, which was located approximately 2.5” above the center point of the sample. The before test distance between the laser and the target was 3.55”. A schematic is shown in Figure 5.

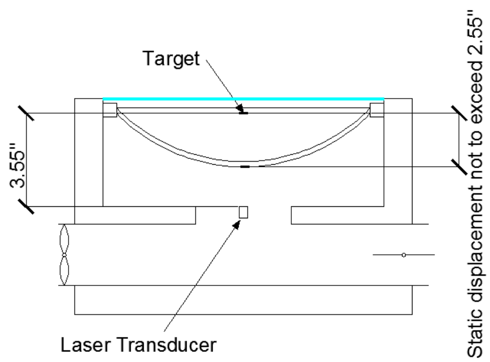


Figure 5: The distance between the laser transducer and target was 3.55” before testing (top) and the static displacement is not to exceed 2.55”; the target (bottom, in red) was placed 2.5” above the center point of the tapestry sample (bottom, blue star).

Throughout the testing, the signal of the laser transducer was used to determine the deflection of the sample while the load cycles were applied. Plots of deflection versus time for the first five minutes and the last five minutes for each pressure level are provided in Appendix A (Note: at some pressure levels the test duration was less than 5 minutes, and thus the final 5 minute time series plot is not provided). **These plots clearly show that the deflection of the target point on the tapestry sample due to applied wind load cycles never exceeded 2.55” during testing. The maximum deflection measured during testing was 0.752” which occurred at an applied pressure of 21.2 psf. This deflection equates to a 0.09% elongation, which is significantly less than the 1% criterion, even through the 1% elongation was intended to be measured when no load is applied to the tapestry sample. As such the criterion is met when loads equivalent to the 100-year wind pressure is applied. Clearly if the criterion is achieved when the 100-year wind pressure is applied, it will also be satisfied under a no-load condition.**

As noted above, RWDI measured the displacement of the sample at low pressure levels in advance and after the full fatigue spectrum was applied. This was conducted to determine the permanent set induced by the fatigue spectrum. Figure 6 shows the time series from the first and last 5 minutes of testing which bracket the full fatigue spectrum of tests. Both tests were conducted at the -6.4 psf pressure level. During the first 5 minutes of testing (as indicated by the red trace in Figure 6), the maximum displacement measured was 0.306" and the minimum was 0.062". The average maxima and minima displacements – that is the average of the maxima and minima during the applied load cycles – were 0.272" and 0.108", respectively. During the last 5 minutes of testing (as indicated by the blue trace in Figure 6), the maximum displacement measured was 0.334" and the minimum was 0.127" whereas the average maxima and minima displacements were 0.313" and 0.145", respectively. These values can be taken as a measure of the permanent deflection between the beginning of the test and end of the test. **Taking the two average maxima displacements of 0.313" and 0.272" from post and pre-testing, and using the Equations (4) and (6) to solve for C_2, it can be shown that this equates to a permanent elongation of 0.004%. Clearly, this is many orders of magnitude less than the 1% criterion.**

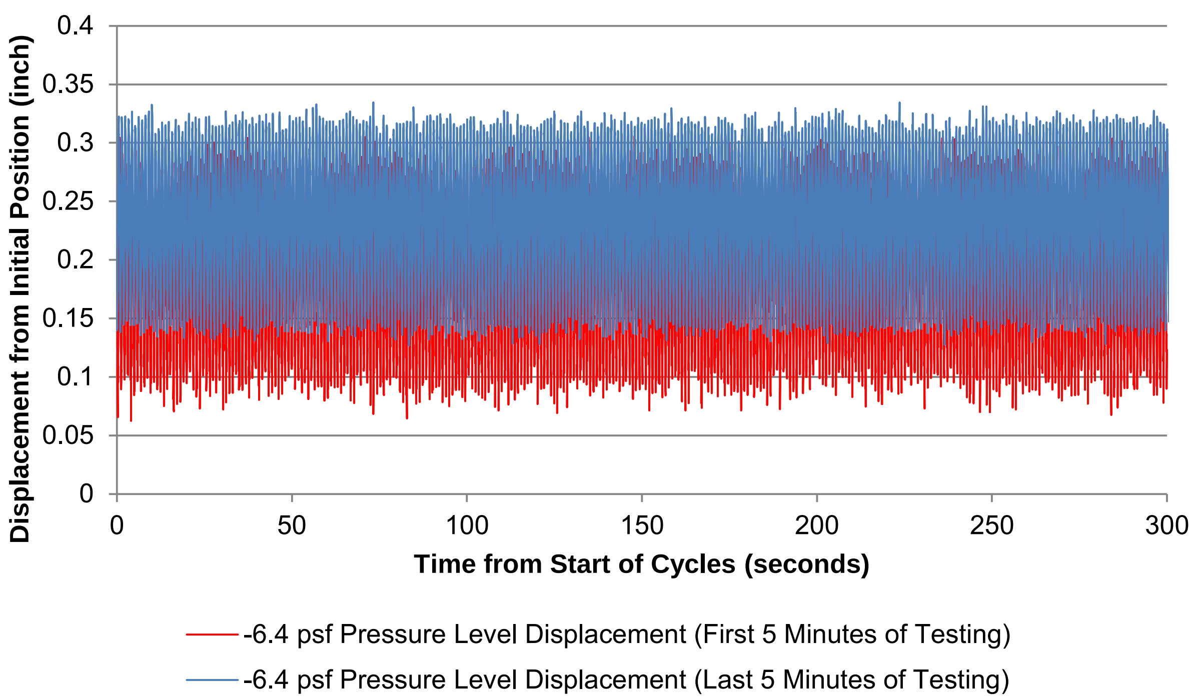


Figure 6: The distance measured by the laser transducer before and after cycles at the indicated pressure levels were applied.

The second criterion in the Najjarine Structures December 31, 2013 report was a visual inspection of the weld joints; the welds between structural (horizontal and vertical) wires, as well as the welds between the structural wires and art wires. From this report, if more than 20% of the welds between structural wires survived after the load cycles are applied, and an aesthetic review of the structural to art wires connections yields no formidable damage, the sample will have passed the criterion.

Visual inspections were conducted by members of the Design Team prior to shipment of the sample to RWDI and then by the Design Team and RWDI following the testing outlined in this document. In the post-test inspection total of 3 structural welds were noted as failed, attributed to testing. **This amounts to approximately 0.3% of the total number of structural welds in the tapestry sample. Therefore, 99.7% of the welds remained intact following application of the load cycles.**

The visual inspection of the tapestry sample did not show any formidable damage. Images of the sample before and after testing are shown in Figure 7.

Figure 7: The tapestry sample before (left) and after (right) testing, with a plexiglas sheet indicating deficiencies in the tapestry sample (left only). The markups on the tapestry sample shown in blue were made by the Design Team before testing.

Concluding Remarks

RWDI has completed fatigue testing of a tapestry sample from the Dwight D. Eisenhower Memorial in Washington, DC for wind pressure cycles associated with the 1-month to 100-year return periods. The tapestry sample underwent testing with application of over 100,000 load cycles, with wind loads ranging from the 1-month to 100-year return period. As part of this spectrum, the design wind load, corresponding to a 100-year return period, was applied to the tapestry a total of 65 times as the applied load cycles were more onerous than the test plan called for. The results of this testing clearly shows that the tapestry sample easily passed the criteria set out by the design team:

- A permanent deformation of 0.004% was found, between the start and end of testing. This many order of magnitudes less than the criterion of 1%;
- The total number of structural weld failures was 3, which equated to approximately 0.03% of all structural welds, and means that 99.7% of the structural welds survived. Again, this is many

order of magnitudes less than the criterion that 20% of the structural welds survive the testing; and,

- A visual inspection of the tapestry sample prior to and following the testing revealed no appreciable damage.

From the results of this testing presented in this report, it can be seen that the tapestry sample performed very well showing no formidable damage, and largely non-permanent deformation. In conclusion, as outlined in this report the applied load cycles have had a negligible impact on the tapestry sample.

If you have any questions please do not hesitate to contact us.

Yours very truly,

ROWAN WILLIAMS DAVIES & IRWIN Inc.

Mike Gibbons, M.E.Sc.
Technical Coordinator

Gregory P. Thompson, M.A.Sc.
Senior Project Manager / Associate

Scott Gamble, P.Eng.
Project Director / Principal

MPG/tyh

APPENDIX A

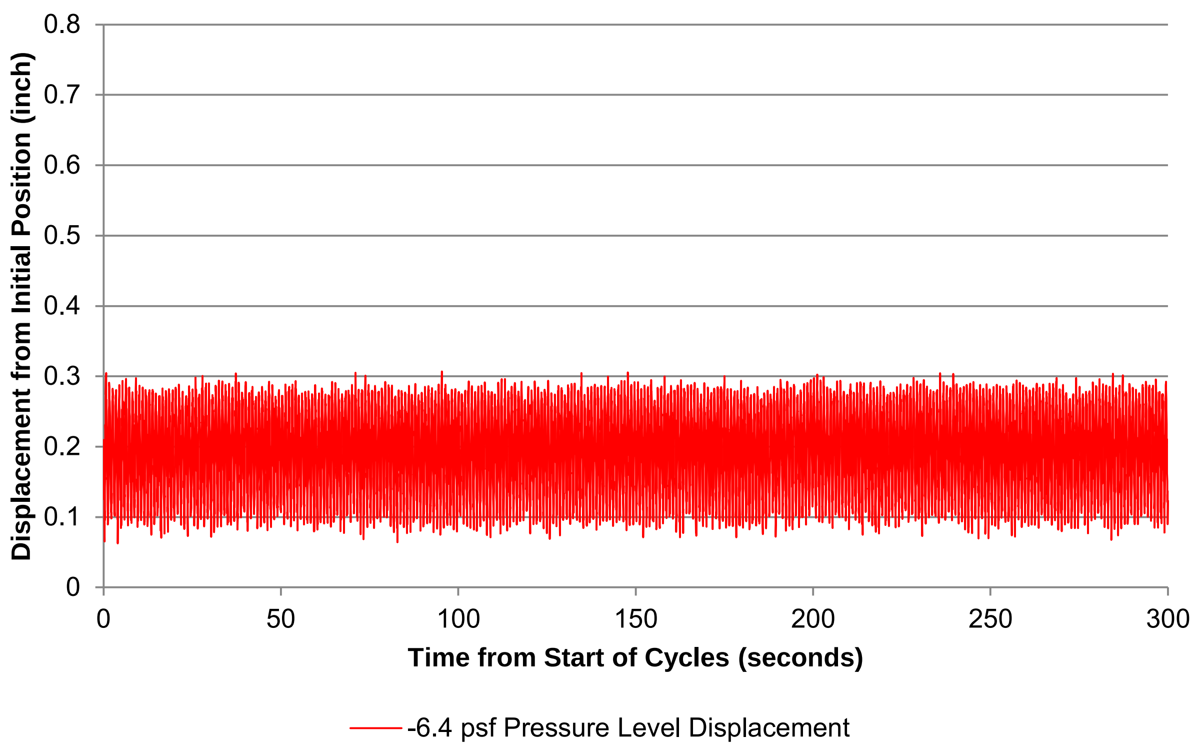
CONSULTING ENGINEERS
& SCIENTISTS

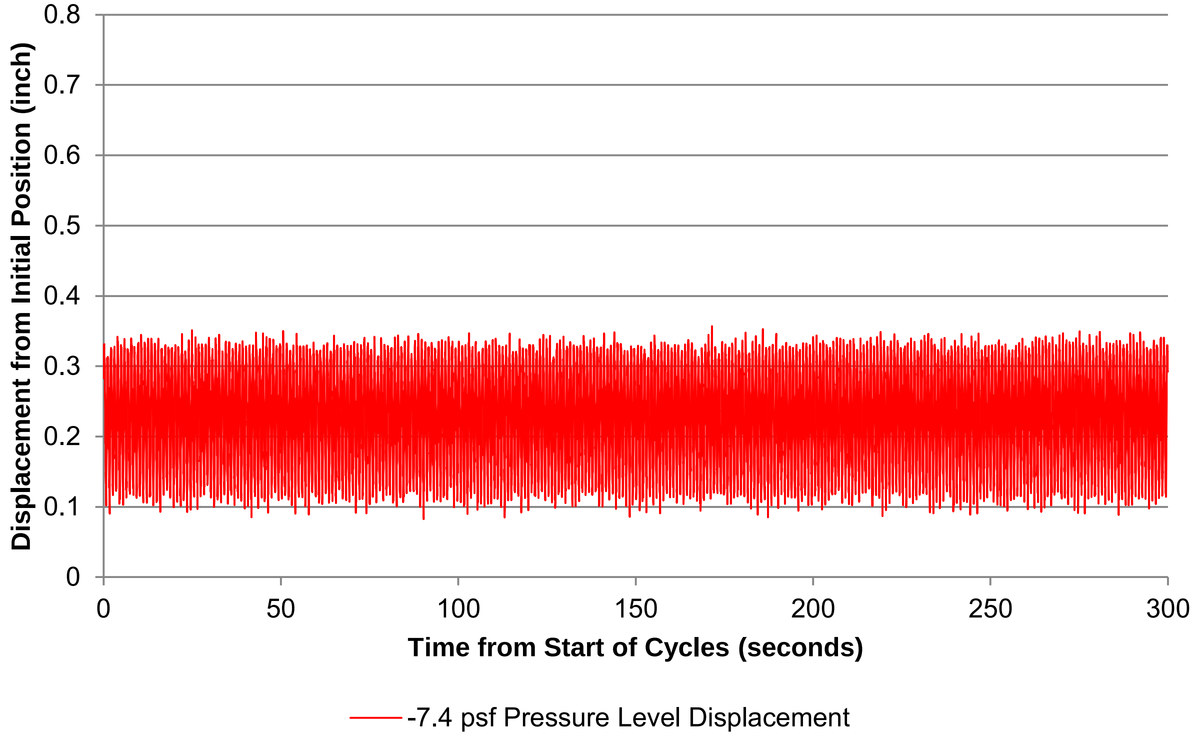
APPENDIX A: MEASURED DISPLACEMENTS FROM FIRST AND LAST 5 MINUTES OF TESTING FOR EACH PRESSURE LEVEL

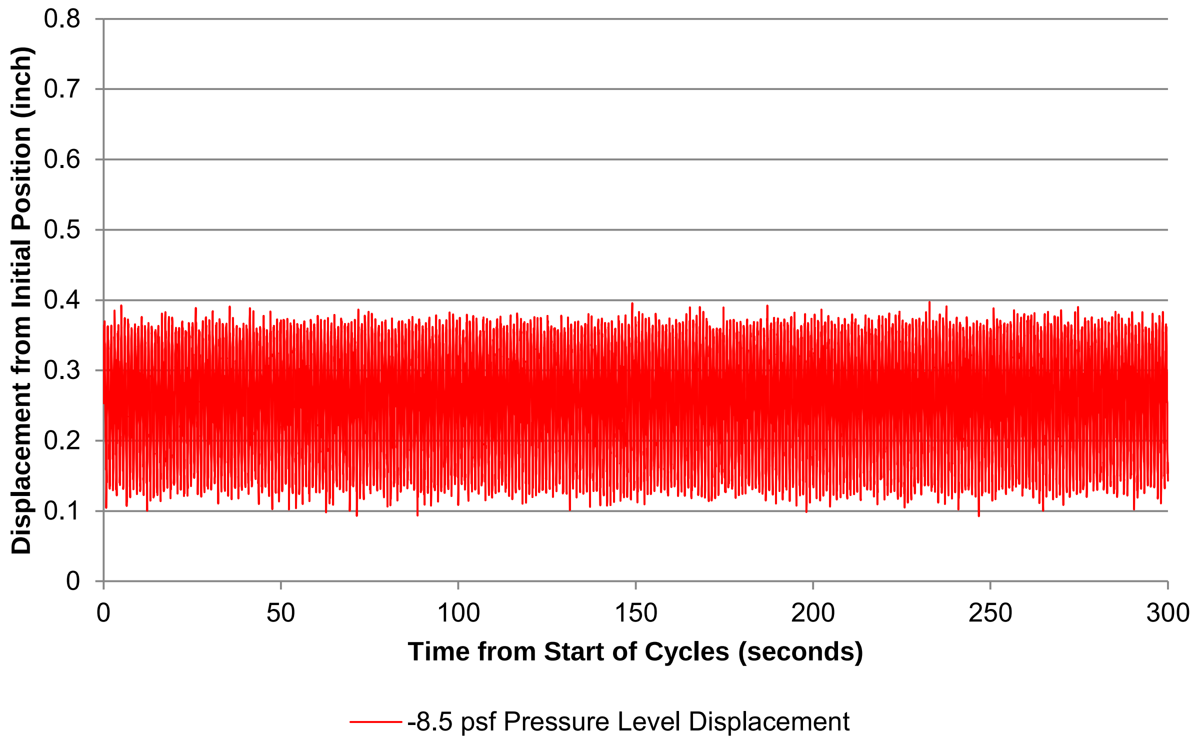
The first five minutes and last five minutes of displacements for each pressure level tested are plotted in the figures on the following pages. Where pressure level test lengths were less than five minutes, only the length of the test is shown.

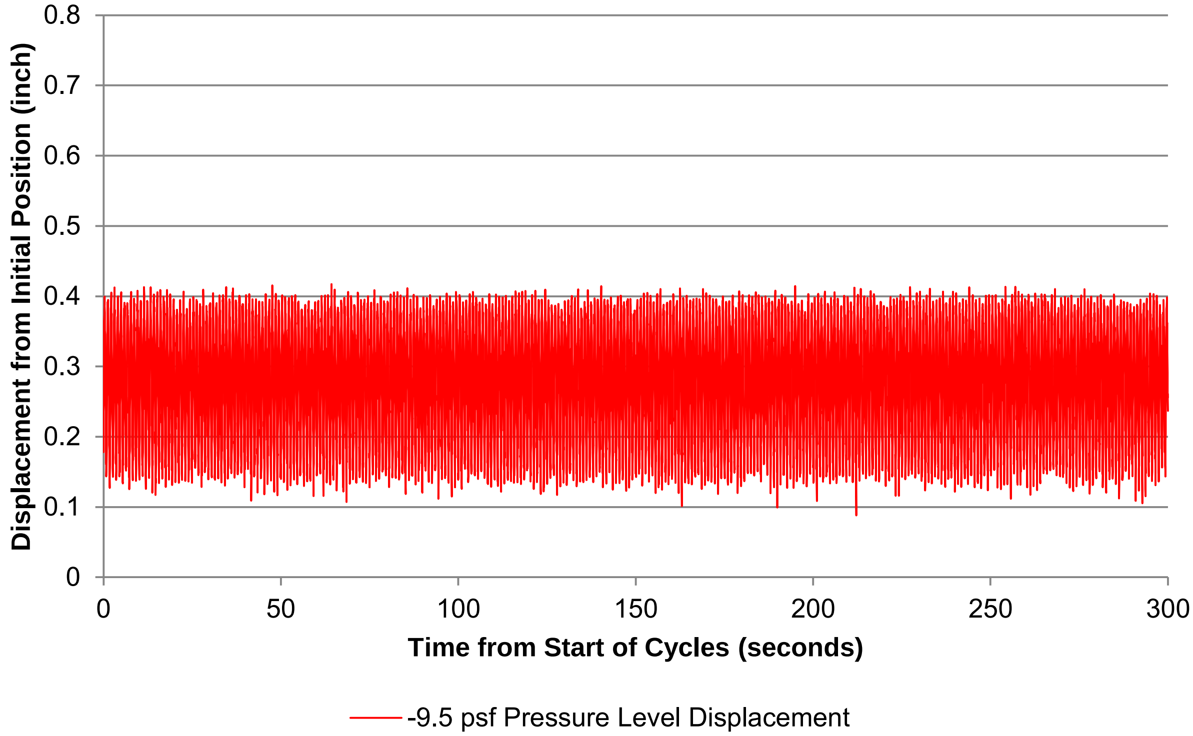
The largest displacement was 0.752" and was measured during the highest pressure level tested, -21.2 psf.

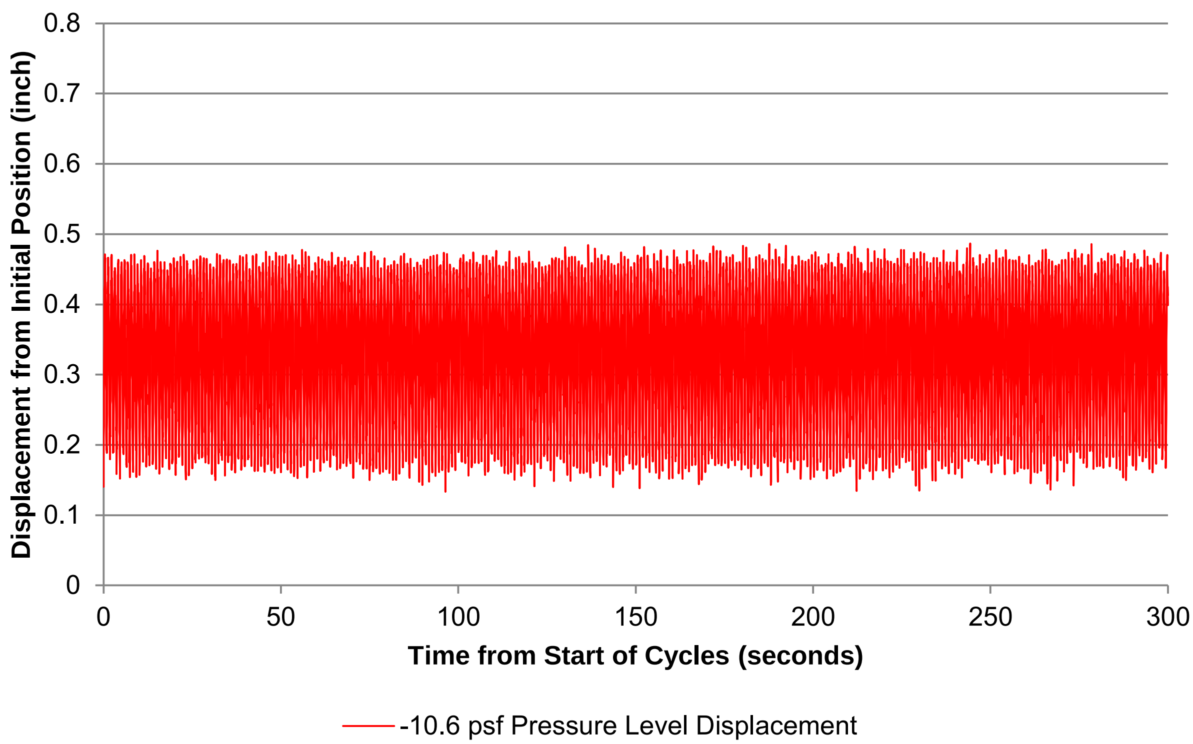
First 5 Minutes:

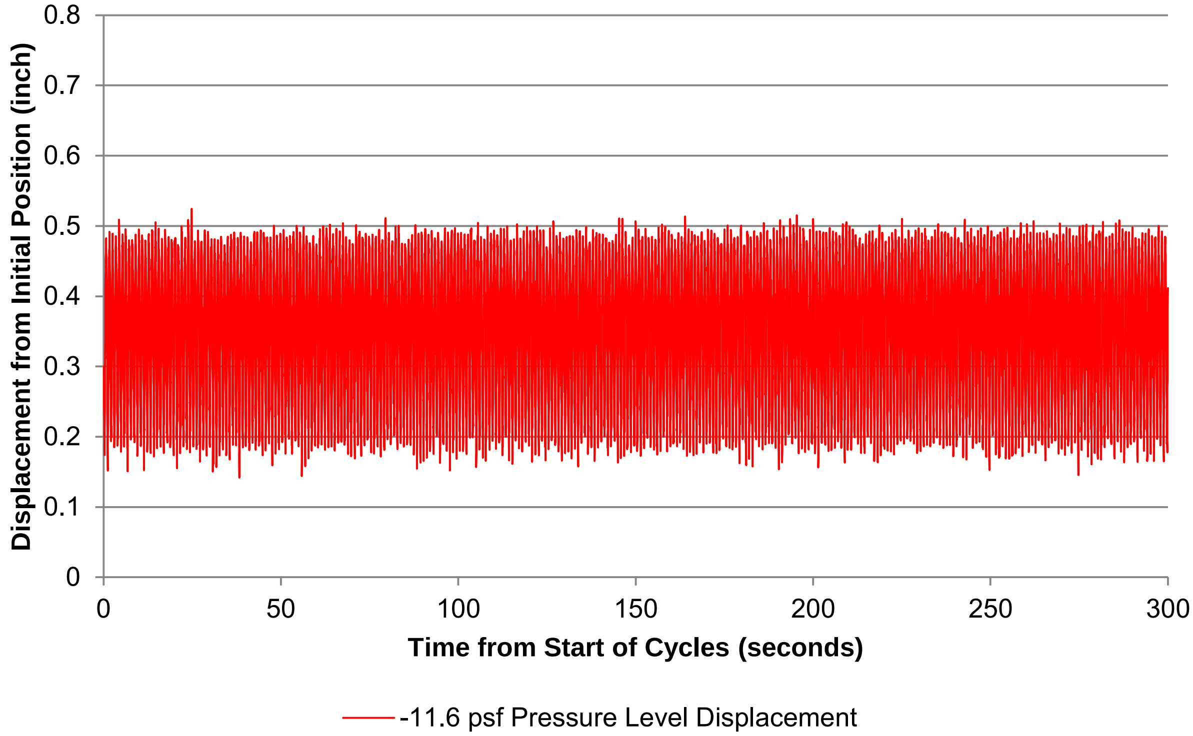


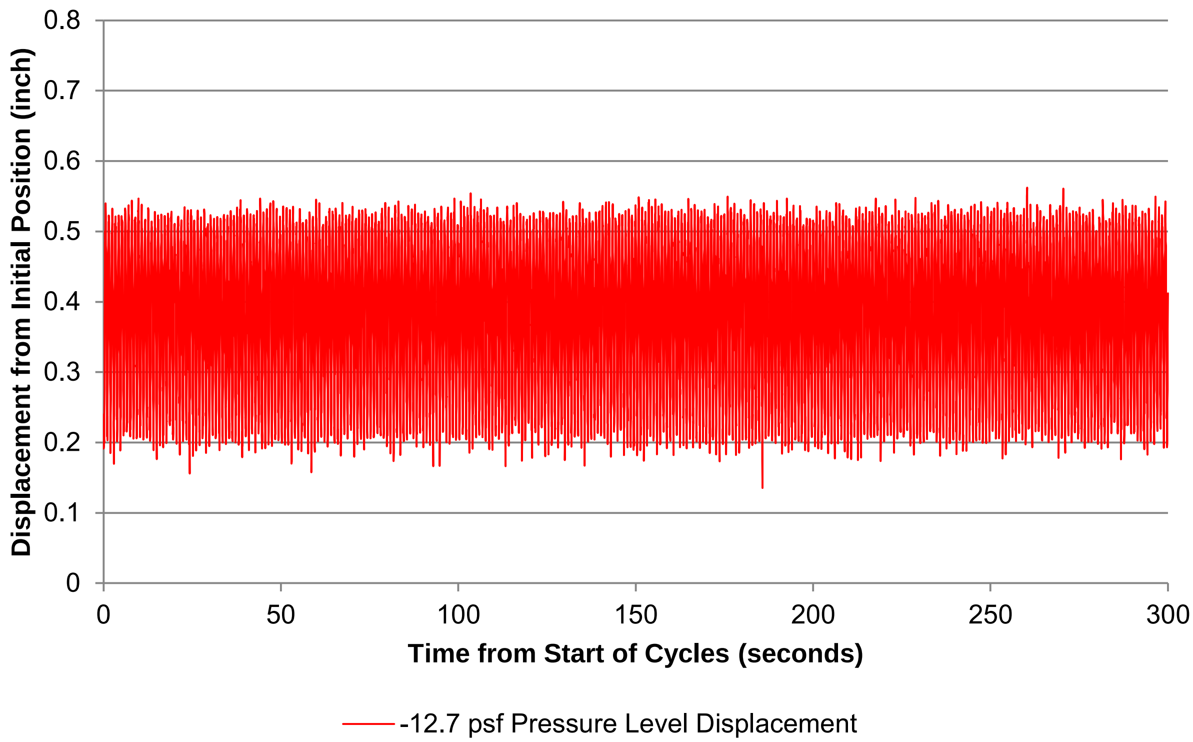

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Displacement from Initial Position (inch)
0
50
100
150
200
250
300
Time from Start of Cycles (seconds)
-7.4 psf Pressure Level Displacement

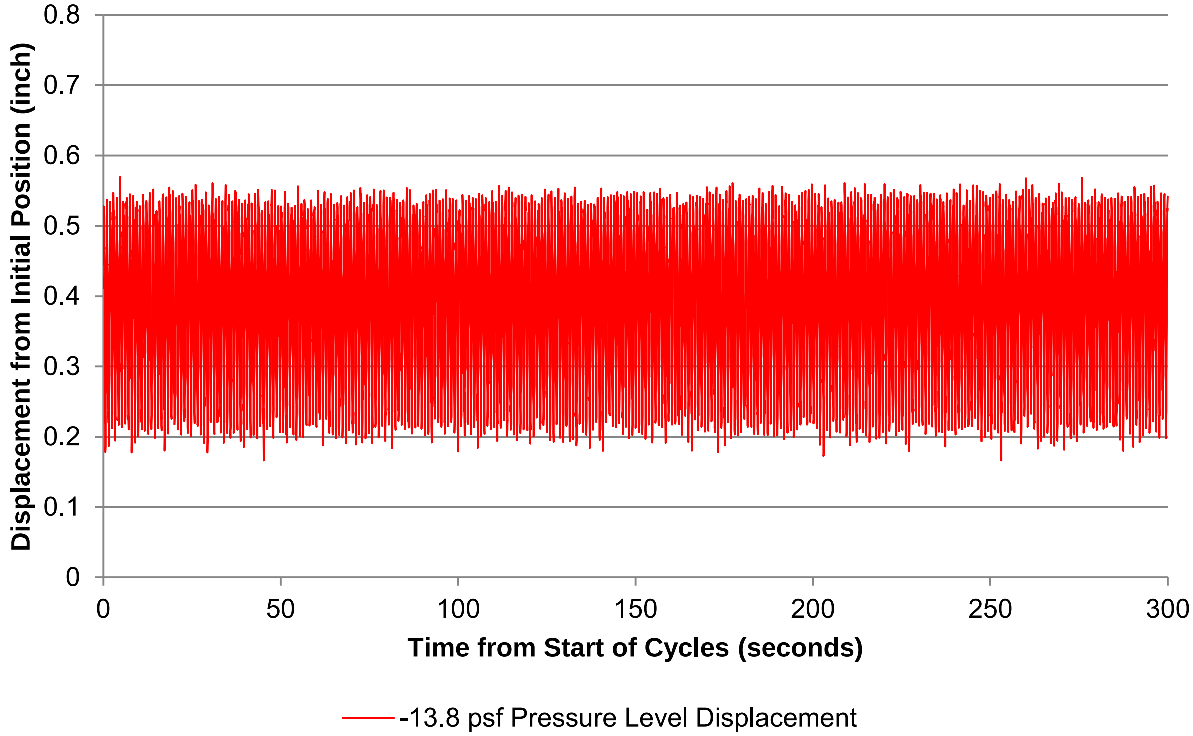

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Displacement from Initial Position (inch)
0
50
100
150
200
250
300
Time from Start of Cycles (seconds)
-8.5 psf Pressure Level Displacement

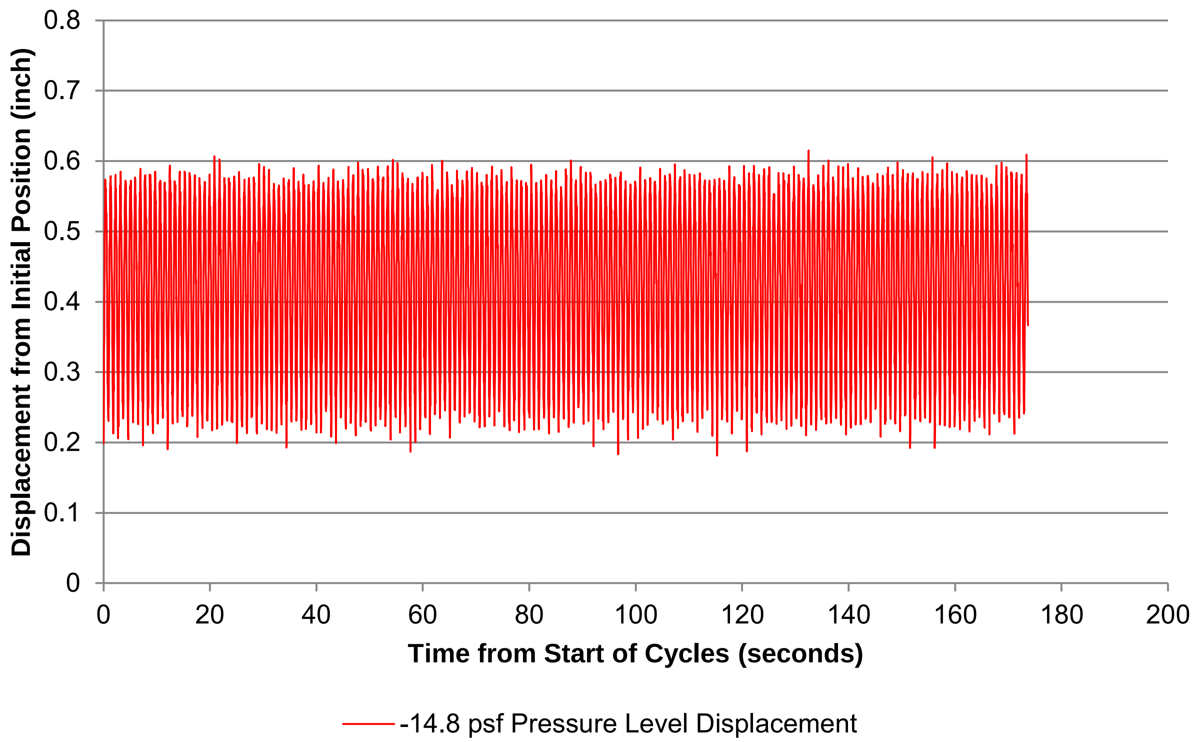

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Displacement from Initial Position (inch)
0
50
100
150
200
250
300
Time from Start of Cycles (seconds)
-9.5 psf Pressure Level Displacement

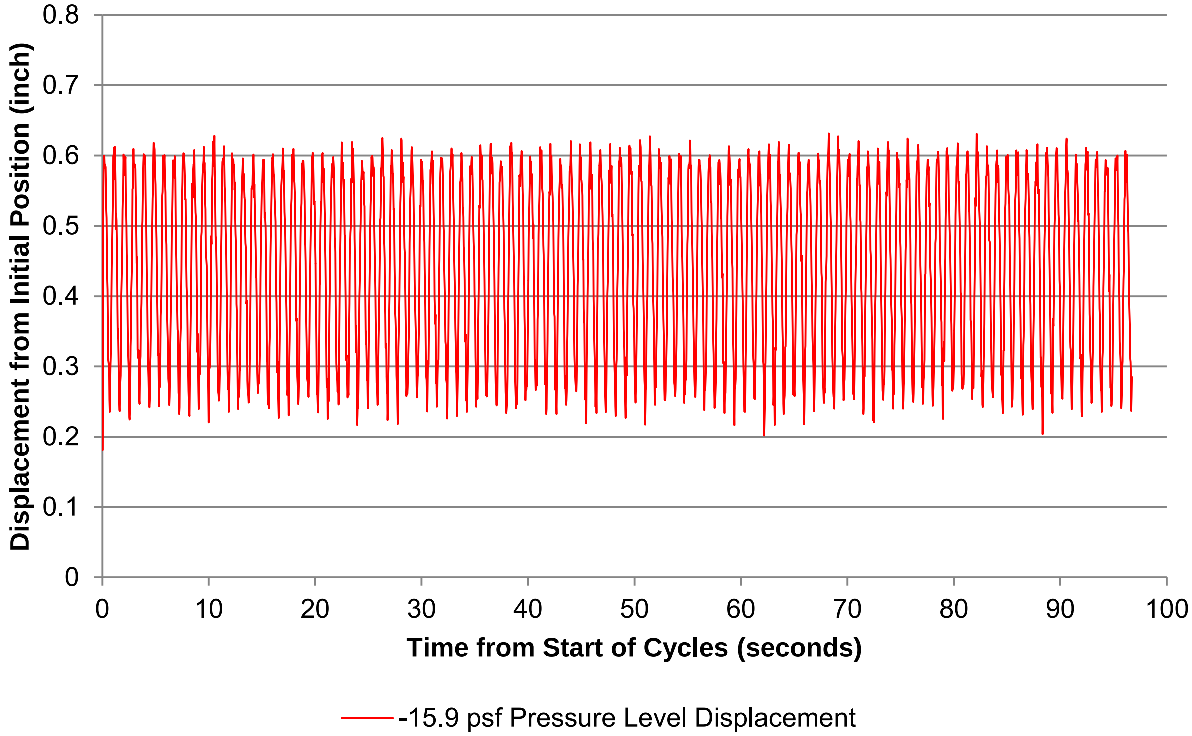

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Displacement from Initial Position (inch)
0
50
100
150
200
250
300
Time from Start of Cycles (seconds)
-10.6 psf Pressure Level Displacement


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Displacement from Initial Position (inch)
0
50
100
150
200
250
300
Time from Start of Cycles (seconds)
-11.6 psf Pressure Level Displacement

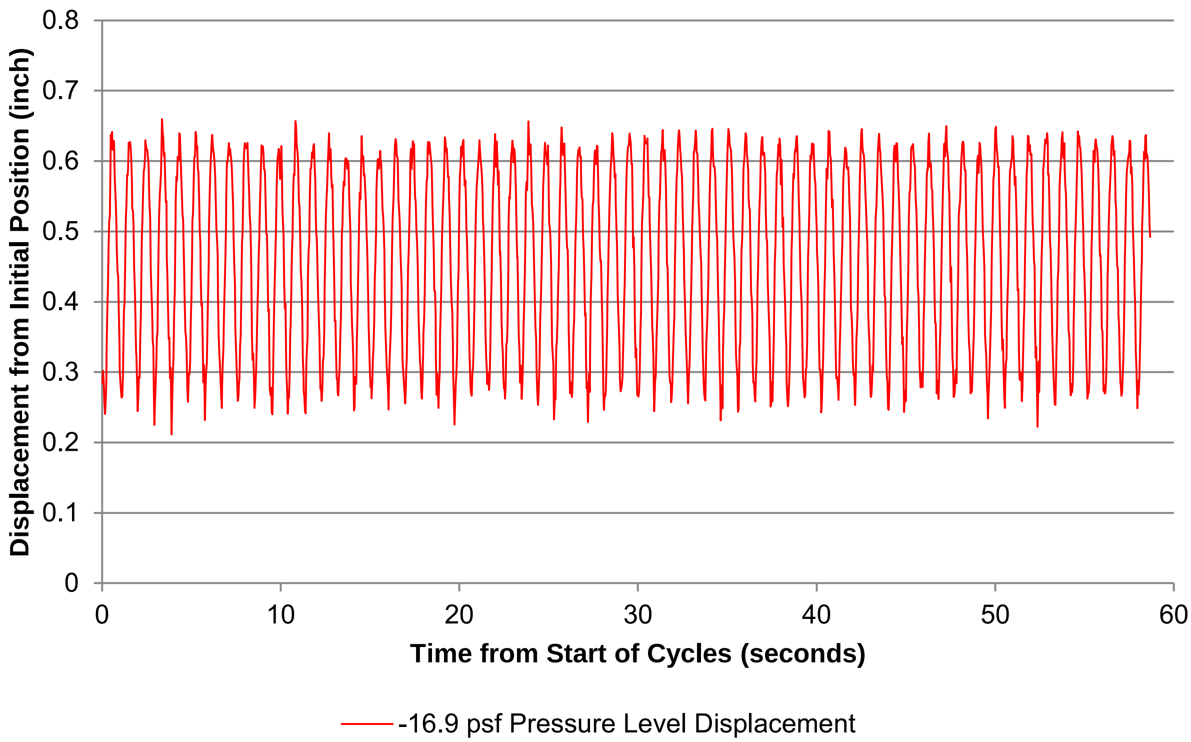

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Displacement from Initial Position (inch)
0
50
100
150
200
250
300
Time from Start of Cycles (seconds)
-12.7 psf Pressure Level Displacement


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Displacement from Initial Position (inch)
0
50
100
150
200
250
300
Time from Start of Cycles (seconds)
-13.8 psf Pressure Level Displacement


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Displacement from Initial Position (inch)
0
20
40
60
80
100
120
140
160
180
200
Time from Start of Cycles (seconds)
-14.8 psf Pressure Level Displacement



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Displacement from Initial Position (inch)
0
10
20
30
40
50
60
70
80
90
100
Time from Start of Cycles (seconds)
-15.9 psf Pressure Level Displacement



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Displacement from Initial Position (inch)
0
10
20
30
40
50
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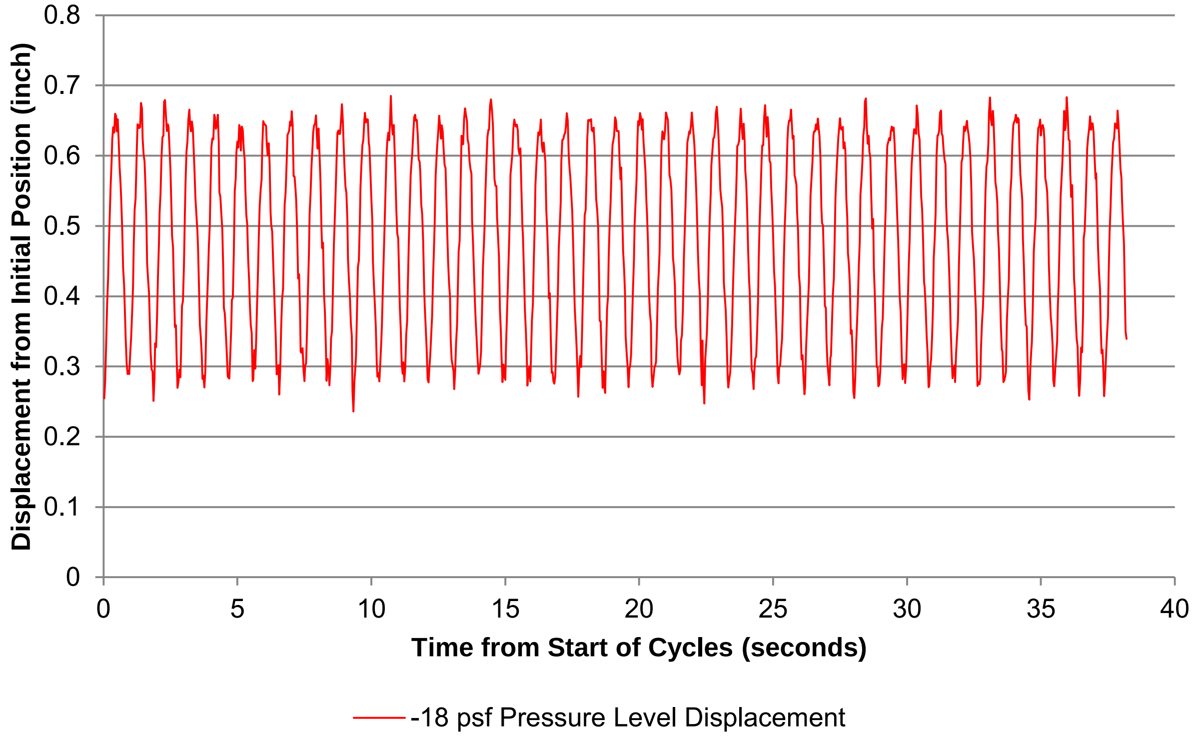
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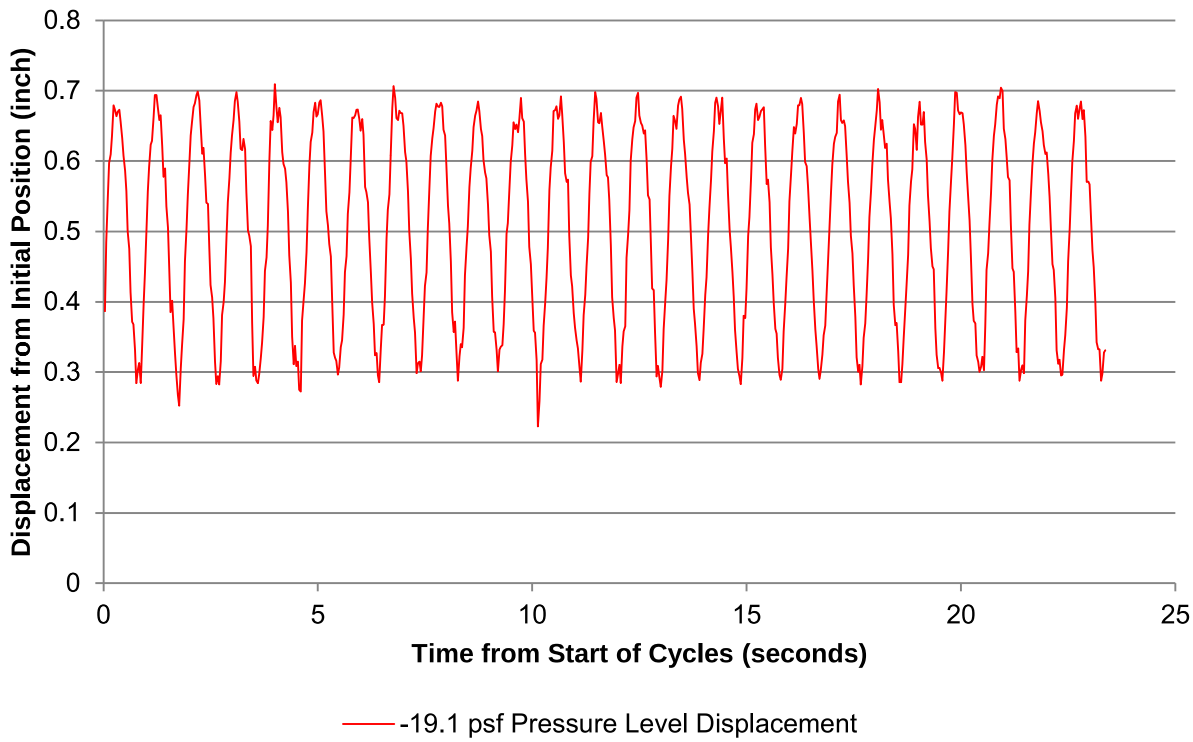
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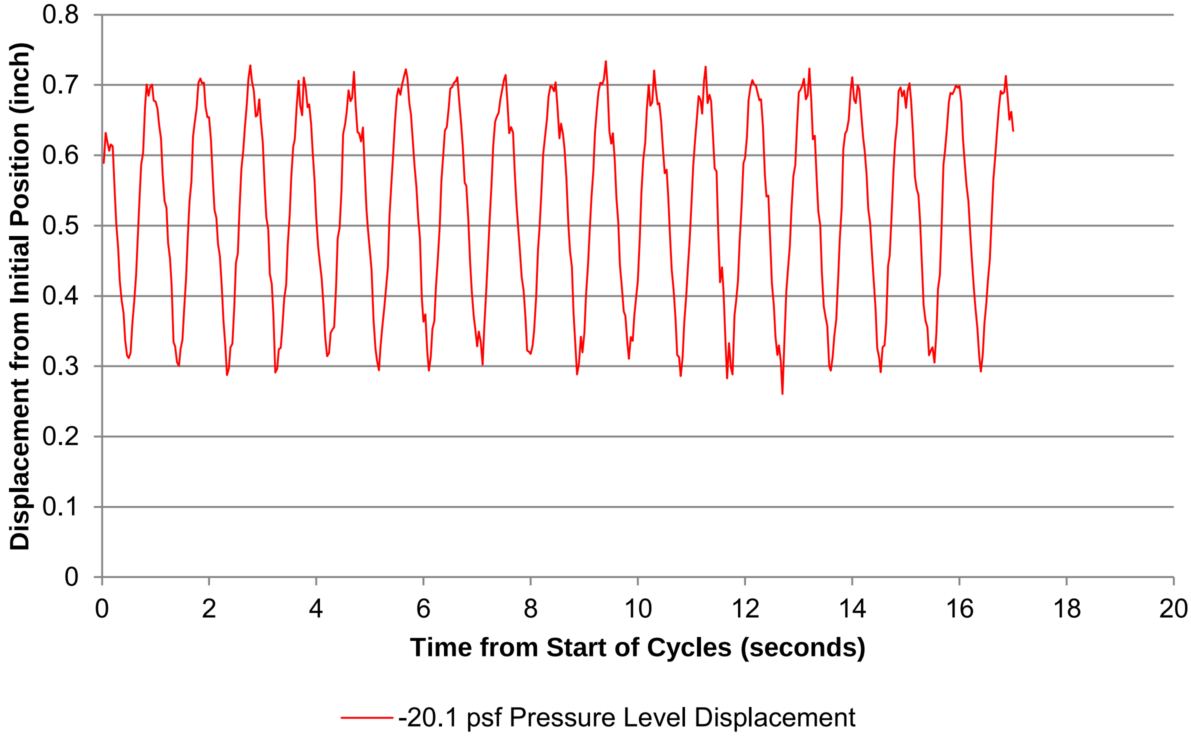
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Time from Start of Cycles (seconds)
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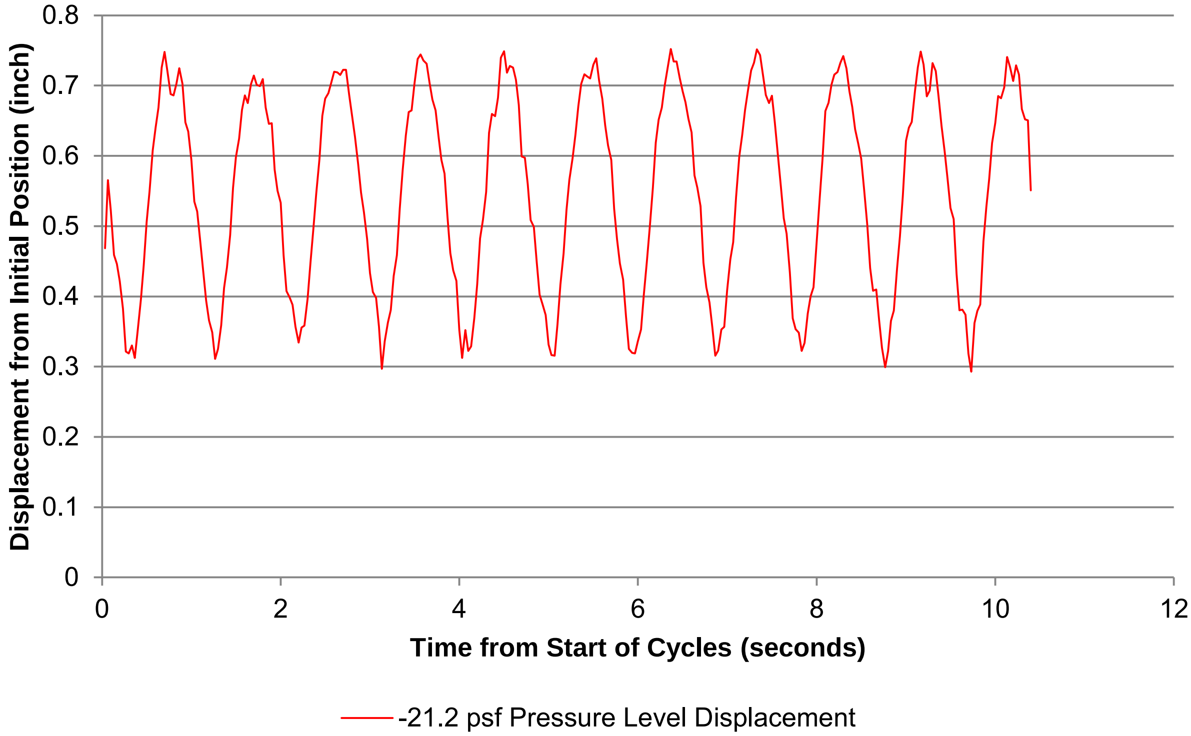
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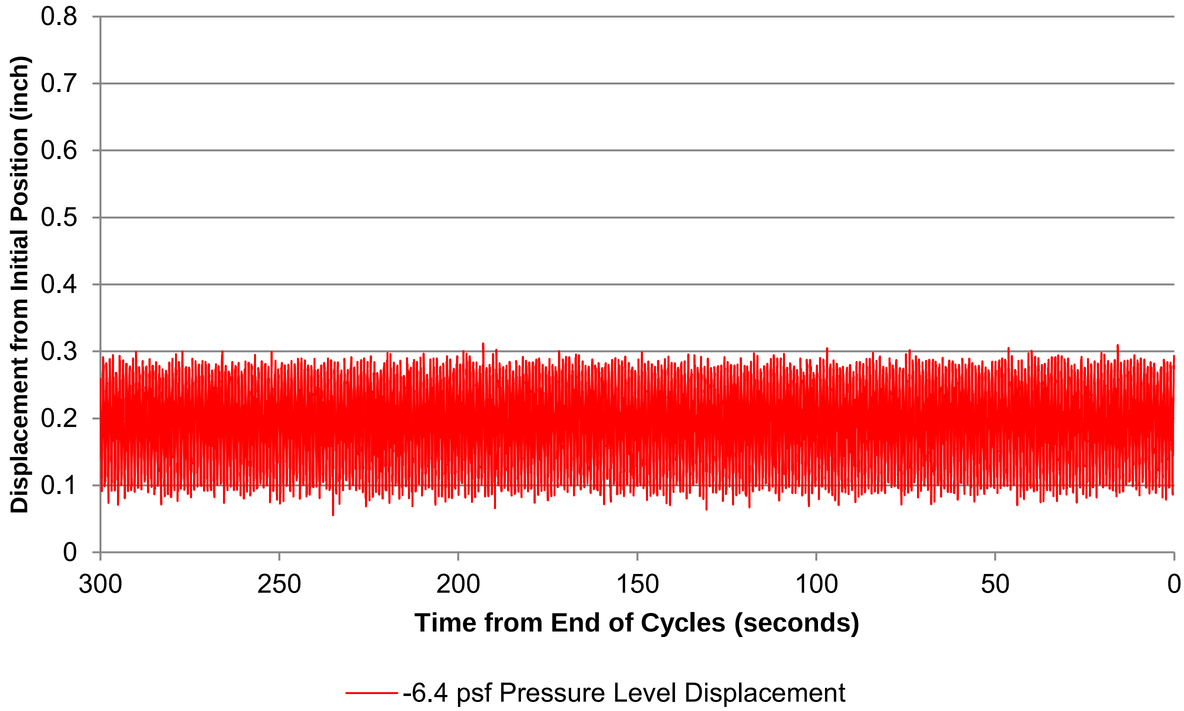
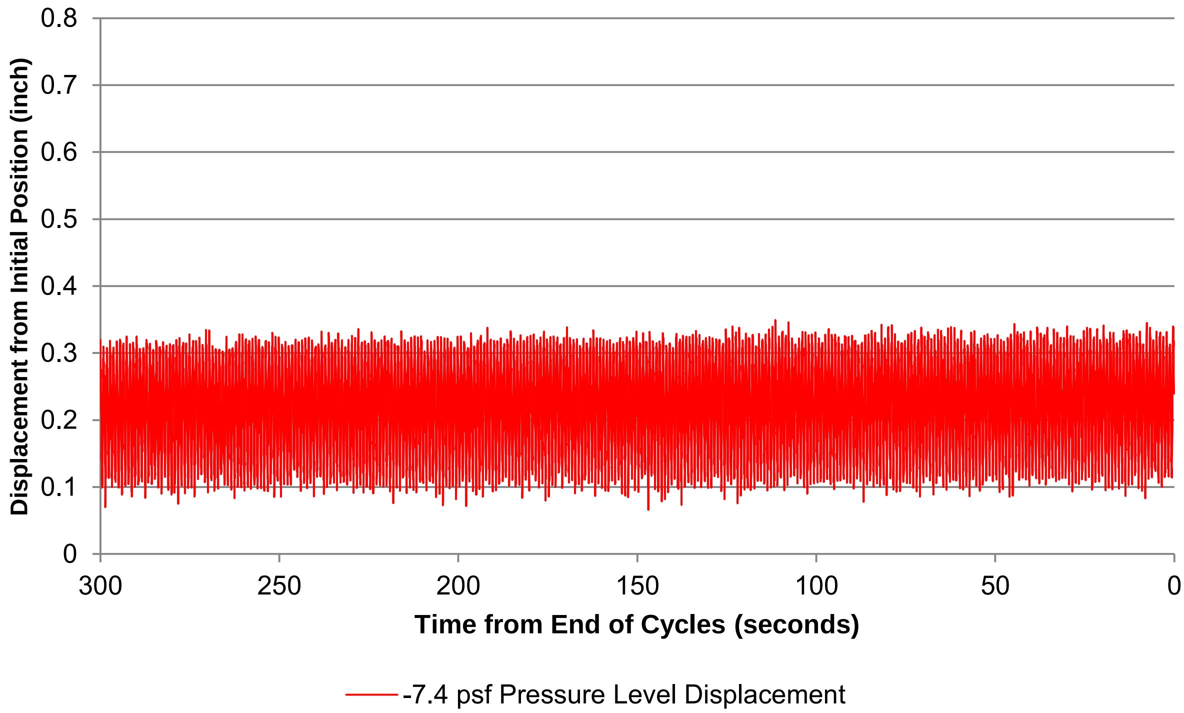
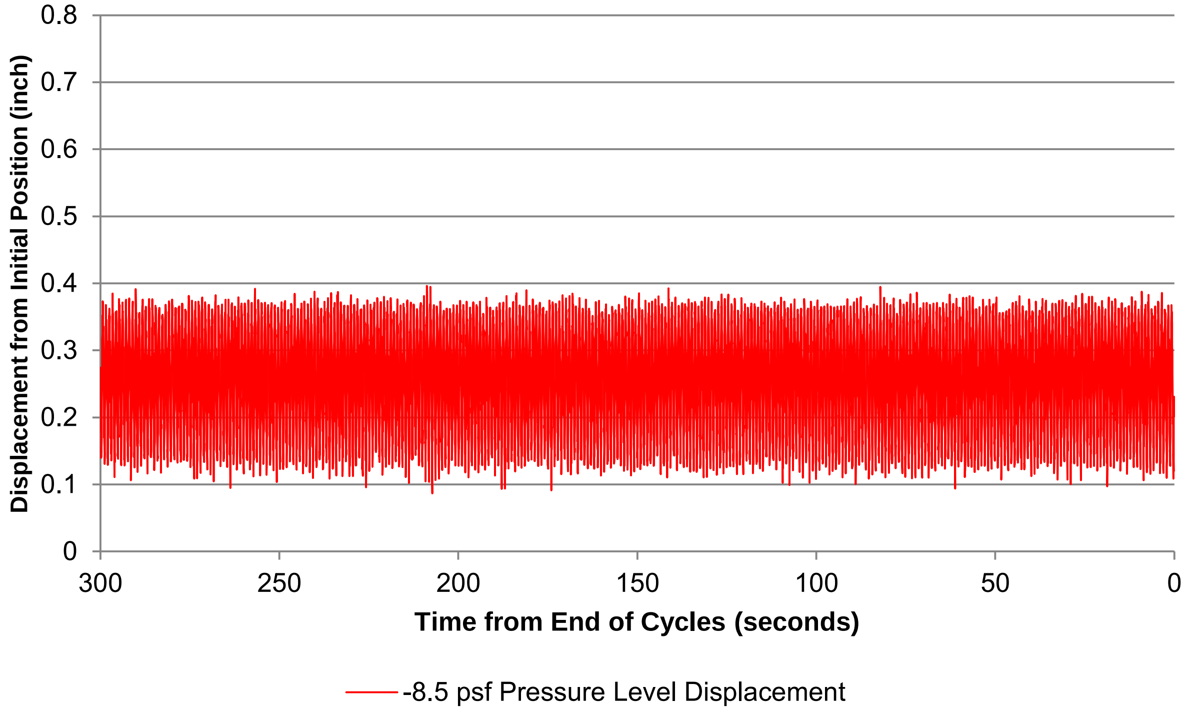
Time from Start of Cycles (seconds)
-21.2 psf Pressure Level Displacement

CONSULTING ENGINEERS & SCIENTISTS

Last 5 Minutes of Testing



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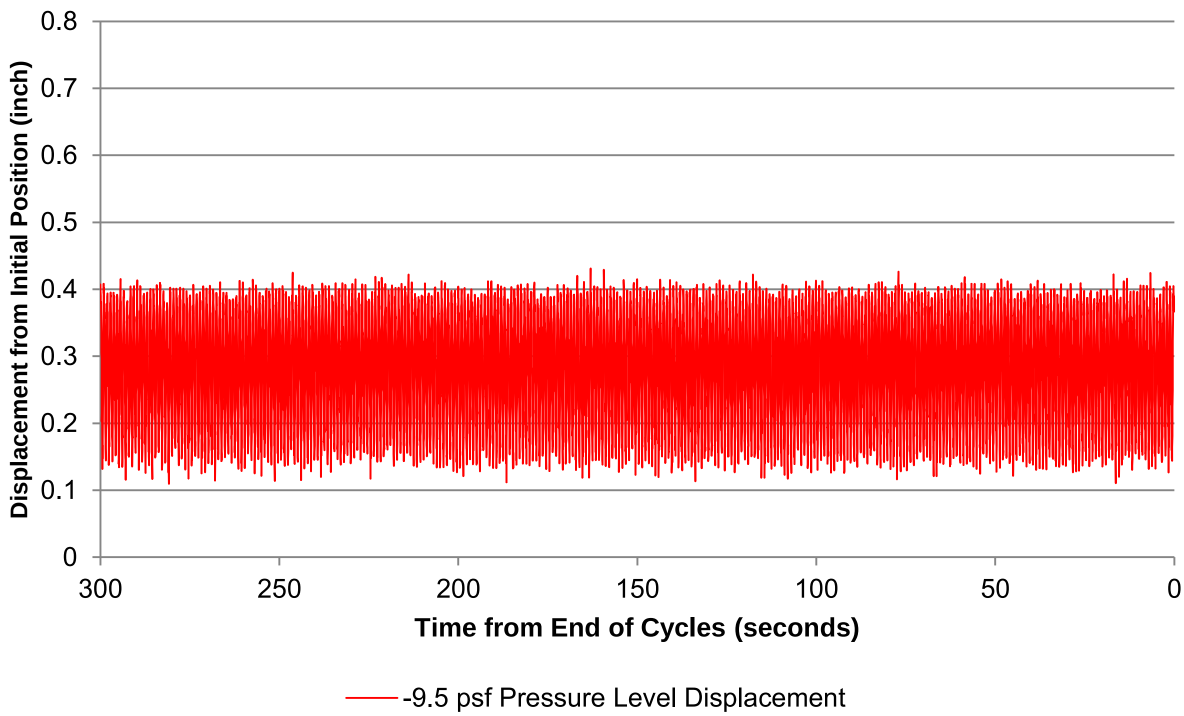
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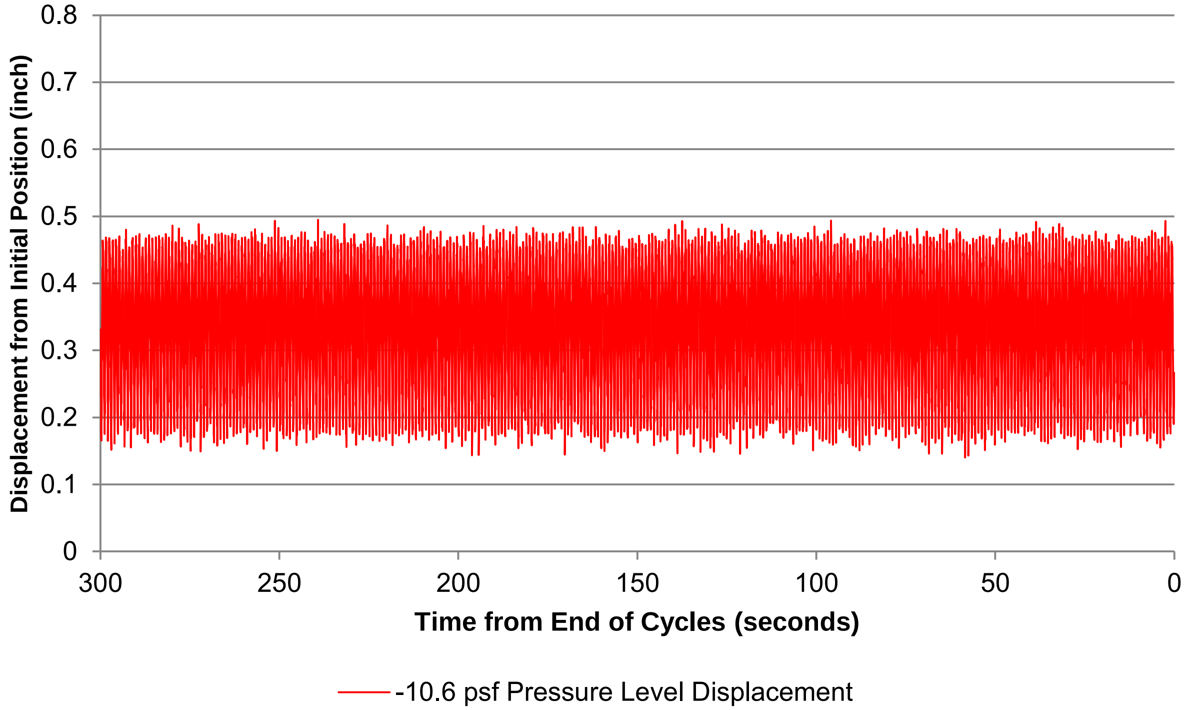
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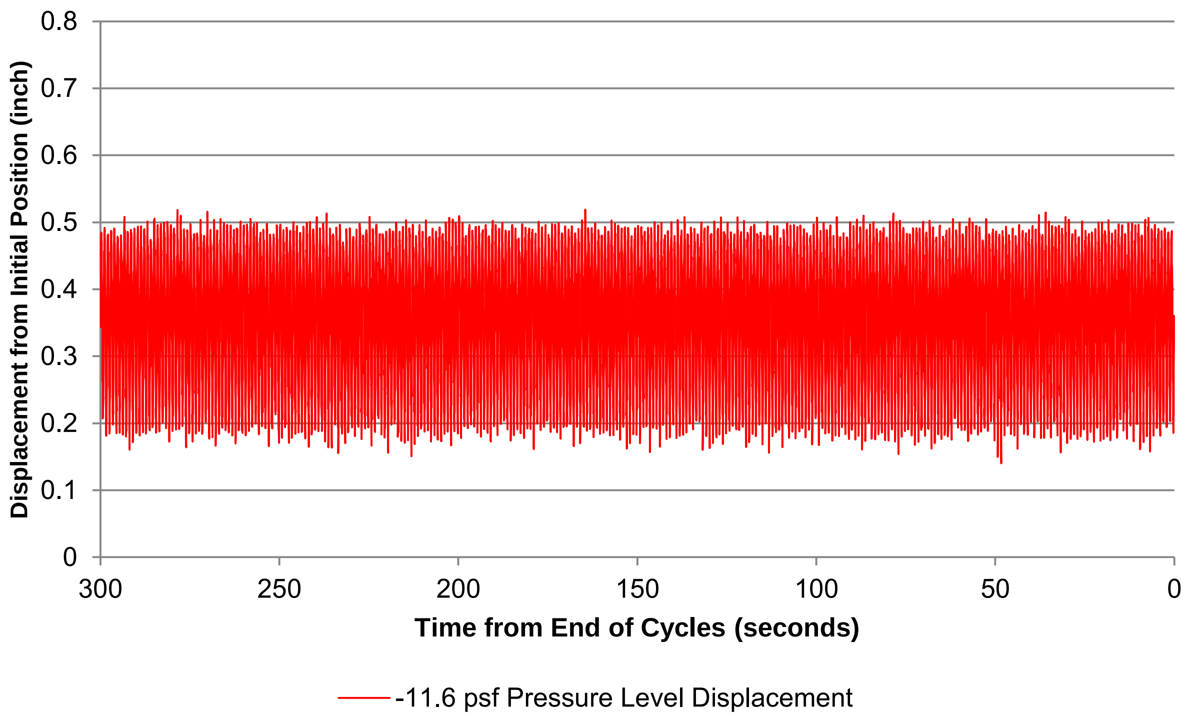
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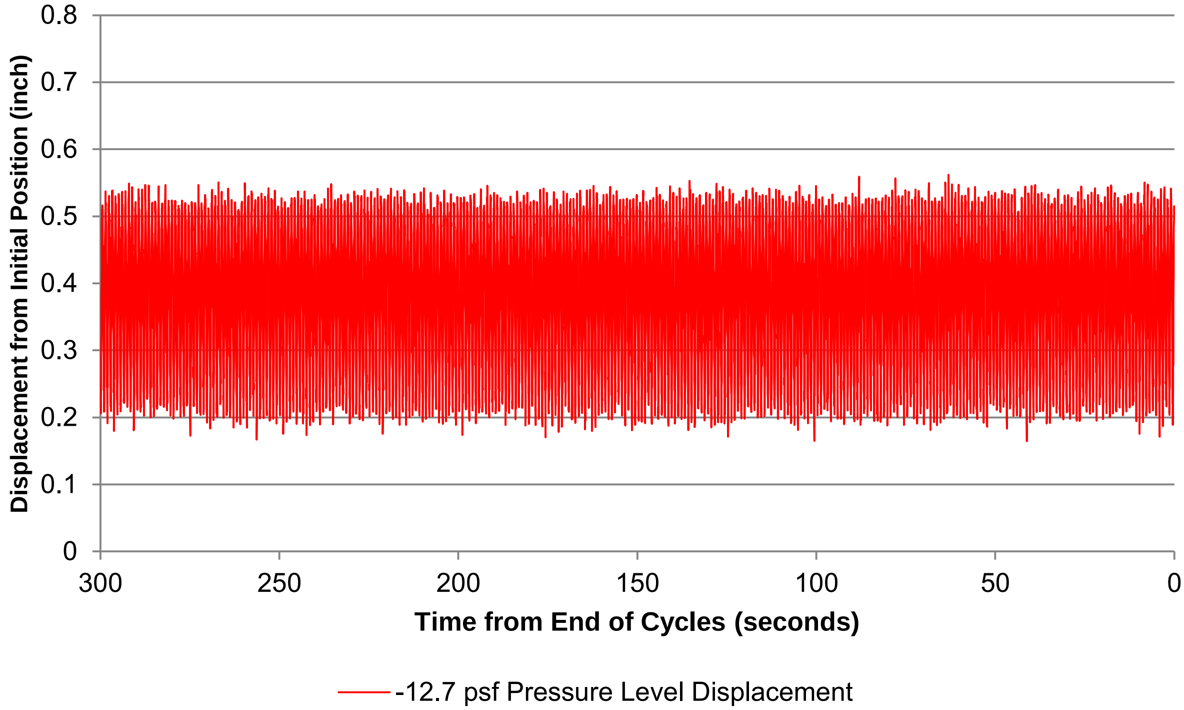
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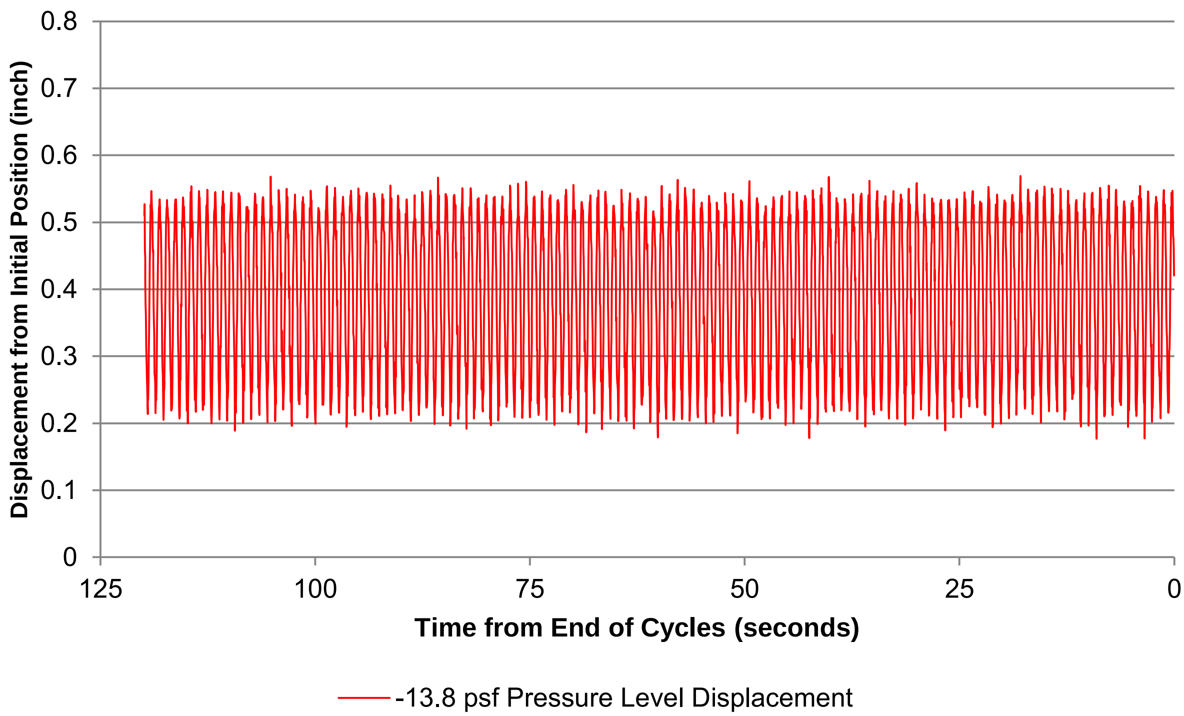
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75
50
25
0
Time from End of Cycles (seconds)
-13.8 psf Pressure Level Displacement

5.2 WEATHER SIMULATION TEST

Included in this section:

- *Final Report - Ice and Snow Consulting Services* from Northern Microclimate

3 February 2014

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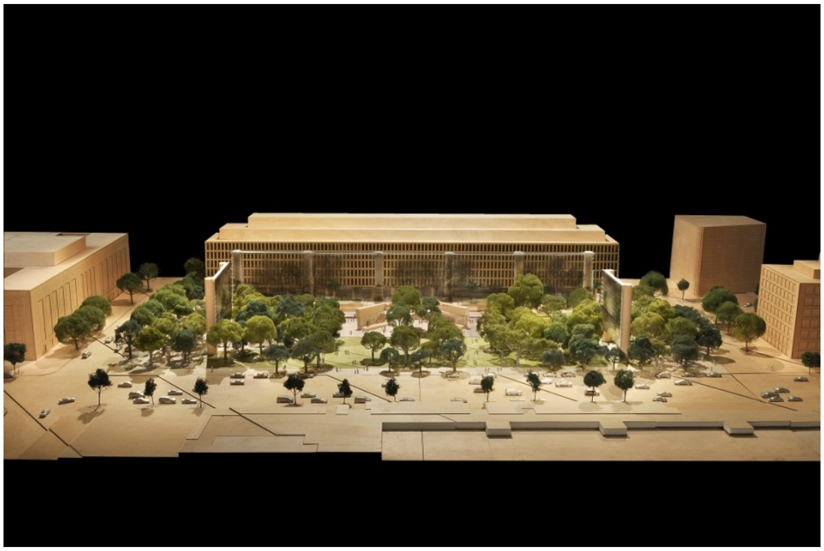

Final Report

Ice and Snow Consulting Services

Re: Design Consultation & Mock-Up Performance Tests

Project: Dwight D. Eisenhower Memorial

Location: Eisenhower Square, Washington DC

Project # N12-4016 & N14-4005

Submitted To:

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Contents

1.0 Executive Summary

Northern Microclimate Inc. was retained by Gehry Partners-AECOM Joint Venture, to conduct Ice and Snow Consulting services for the proposed Dwight D. Eisenhower Memorial in Eisenhower Square, Washington DC. The purpose was to assess the potential for falling, sliding, or windblown ice and snow from the proposed project site structures and buildings; in addition to Mock-up Performance Tests intended to investigate and develop guidelines for the final design of the Tapestries.

Overall, the results and findings of the work performed served to develop; recommendations, design modifications, additional features, and guidelines that have all been incorporated and/or accepted into the final design of the project site and tapestries.

In direct response to the inquiry of the external review agencies the following; actions taken, findings, and recommendations are summarized:

- Historical and local microclimate analysis of wind, snow, rain, and ice from freezing rain has been incorporated into experienced based consultation and laboratory test procedures.
- Seventeen (17) cold room laboratory tests were completed, each with multiple samples and/or configurations, conducted in three (3) separate iterations that allowed for multiple stages of design refinement and validation.
- Guidelines and recommendations have been developed for all aspects of the project site.
- It was found that the refined design of the Tapestry Base Assembly resulted in positive correlation with samples of architectural mesh or screens that are commonly used in the building industry, and have not been reported to be problematic in winter weather.
- It was found that the addition of the Tapestry Art Work, following the proposed guidelines and recommendations, further improved the winter performance of the overall tapestry.
- It was found that the geometries of both the Tapestry Base Assembly and the Tapestry Art Work, as documented within this report, provide additional attachment and segmentation of accumulations, promoting a melt in place strategy, releasing (if at all) as small and individual formation at the end of the melting period when their mass is diminished.
- To address any accumulations or potential for refreezing of melt water on walking surfaces, under pavement heating has been added to the design in areas local to the base of the tapestries.

In conclusion, it is our opinion that the implementation of the design modifications, recommendations, and guidelines contained within this report will significantly reduce the potential for winter performance issues.

1.0 Introduction

Northern Microclimate Inc. was retained by Gehry Partners-AECOM Joint Venture, to conduct Ice and Snow Consulting services for the proposed Dwight D. Eisenhower Memorial in Eisenhower Square, Washington DC. The requested scope of work included a falling, sliding, or windblown Ice and Snow Assessment for the proposed structures and buildings; in addition to Mock-up Performance Tests intended to investigate and develop guidelines for the final design of the Tapestries.

The objectives of the Ice and Snow Assessment and Mock-up Performance Tests were to:

- perform an analysis of historical meteorological conditions, estimating local microclimate influences on potential ice and snow formations at the project site;
- review design drawings to identify aspects of the design that could accumulate and release ice and snow formations;
- provide recommendations intended to reduce the potential for ice and snow formation and release, through design modifications, mitigation measures, and/or management strategies;
- conduct Mock-up Performance Tests of on the original Proof of Concept Aesthetic Mock-up and multiple subsequent Tapestry Samples investigating winter performance; and,
- develop guidelines for the final design based on test results, integrating the tapestry design with the local microclimate, incorporating strategies for reduced accumulations and safe release of formations that due occur.

Therefore, the purpose of Northern Microclimate's scope of work is to provide the design team with test results and experience-based consultation for ice and snow mitigation and management. Accordingly, the following report has been structured to illustrate the methodology used by Northern Microclimate, capturing the design team's desired balance of risk, cost and aesthetics, accomplishing the stated purpose.

2.0 Background Information

The prediction, identification, and mitigation of ice and snow formations on a proposed building or structure during design, is largely an experience-based endeavor. Subsequently, an assessment combines the following aspects:

- analysis and interpretation of historical meteorological conditions from local meteorological station data;
- an experience-based prediction of the microclimate wind flows during winter storm events in the vicinity of the proposed project site;
- a review of the proposed structure and building details as illustrated in the architectural drawings;

- the proposed accessibility and/or usage of the project site;
- an understanding of local perception or sensitivity to winter storm conditions; and,
- an assessment of the design team and owner's desired balance of physical mitigation versus available operational management strategies, regarding winter performance.

The accumulation and potential for release of ice and snow from any building or structure cannot be prevented; only reduced in frequency and severity. Furthermore, there are limited regulatory codes or industry standards in which to guide a design in this regard. Consequently, the services documented herein have relied on a collaborative process between Northern Microclimate and the design team while conducting investigative testing, design modifications, and recommendations for future winter operations and management practices of the completed project.

It is further important to note that the services documented herein do not pertain to structural snow load aspects of building design. Issues associated with falling, sliding, and windblown ice and snow are related to the serviceability of the site and are therefore assessed using a shorter return period or frequency of weather event versus that of structural snow loads. It is generally accepted that during less frequent, however more extreme events, ice and snow related issues are handled with operational protocols and maintenance; and, that people or site visitors are aware of potential weather related issues, and accept reduced operations during and directly after severe winter storm events.

3.0 Design Consultation Summary

The following summarizes the key tasks and consultation sessions that were accomplished with the design team:

- An initial review of the available detailed design drawings was conducted in conjunction with a long-term historical meteorological analysis. The analysis included a presentation of relevant historical meteorological records and interpretation of the local microclimate conditions at the site (refers to Appendix A, Slides 1 through 7). Details regarding this analysis are discussed in Sections 3.1 and 3.2 below. This analysis along with concepts for ice or snow mitigation strategies was then communicated by way of a conference call. The intent of this first consultation session was to establish the preferred strategy for ice and snow mitigation on project structures and buildings; and, to discuss a preliminary test schedule for the Mock-up Performance Tests of Tapestry Samples.

- A second consultation was conducted via conference call and focused on mitigation recommendations for the project structures and buildings, as well as, a review of the recommended test plan for the Mock-up Performance Tests. During this meeting, it was decided to include a sample of the proposed stone that will be used for project structure and building components, to determine if the flamed finish will act as a rough surface to melting ice and snow.

- The Mock-up Performance testing was then conducted in three (3) iterations, starting with a calibration and investigation tests conducted in late March and early April 8th, 2013. Knowledge gained from the first testing period was then analyzed, reviewed and incorporated into the next two iterations where design improvements were tested on additional Tapestry Samples. These tests occurred between January 13th and January 29th, 2014. Details regarding the Mock-up Performance Tests are discussed below in Section 4.

- The Mock-up Performance Tests and design consultations were then collected, analyzed, and summarized for this report.

3.1 Analysis of Historical Meteorological Statistics

Historical Meteorological statistics and analysis based on data from Dulles International Airport and Ronald Reagan Washington National Airport were prepared for presentation during the initial consultation. Tabular and graphical slides can be reviewed in the presentation included in Appendix A (refer to Slides 1 through 7). The presented information covers topics such as: graphical presentations of winter wind frequency and speeds during various conditions; seasonal snowfall statistics and averages; and, descriptions of typical winter storm scenarios. The overall focus of the analysis was to present to the design team the anticipated frequencies and severity of the various winter precipitation scenarios that can initiate falling, sliding or windblown ice and snow. This information provided the basis for the mitigation strategies presented in Section 3.3 of this report.

3.2 Winter Weather & Local Microclimate Conditions

Winter weather conditions in the Washington, DC area historically produce multiple occurrences of ice and snow formation, followed by melting periods, on buildings and structures, throughout a typical winter season. The main reason for this cyclical condition is the proximity to the Atlantic Ocean and the Appalachian Mountains, creating a tendency for winter storms with high precipitation followed by a sudden rise or fall of air temperatures in the following hours/days. These characteristics lead to multiple events of snow accumulation, ice generation, and melting throughout the winter season, increasing the probability of occurrences of falling ice and snow. The various events that can contribute to different forms of ice and snow issues can be summarized as:

- snowfall with lower winds that melts away in favorable weather that follows;
- a winter storm with high winds and driving snow that melts away in favorable weather that follows;
- a winter storm that is followed by cold clear days of below freezing temperatures;
- consecutive winter storms or days with snowfall that include fluctuating air temperatures, producing melt and re-freeze conditions; or,
- a winter storm comprised of wind driven freezing rain or sleet.

Each of these events can produce different ice or snow related issues, and therefore have been anticipated in both the review of drawing details and the Mock-up Performance Test Plan.

3.3 Review of Current Design Drawing Details

Recommendations outlining mitigation measures for the proposed project structures and buildings have been discussed with the design team and are presented in Appendix A, slides 8 through 11. Some of the recommendations are provided for incorporation directly into the architectural design drawings, while others are presented as guidelines for work to be completed by others later in the design process. The following bullets provide a summary of the recommended mitigation strategies:

- Snow retention devices in the form of a raised-angled bar barrier to retain accumulated ice and snow, while allowing melt water to drain from the top surfaces of the columns and support structure; have been provided on slides 8 and 9.
- A design modification to the 4" x 6" structural lighting support, changing its orientation from horizontal to sloped (approx. 15°), with the addition of a raised-angled bar barrier between light supports, has been provided on Slide 10. The added slope will encourage melt water drainage, while the bar barrier will retain ice/snow formations.
- Guidelines and/or mitigation measures, for the various smaller support elements that connect the tapestry support cables to the columns have been provided on Slide 10. These guidelines focus on modifying the size and shape of elements towards smaller surfaces, rounded or sloped top surfaces, and a preference towards vertical orientation rather than horizontal orientation.

Recommendations for the Memorial Block, along with other stone parapets are provided on slide 11. They include recommendations that the tops be specified as rough surfaces to reduce potential sliding of ice and snow. It was decided to send a stone sample to the cold room for testing that resulted in a recommendation to provide or apply a roughened surface treatment (e.g., sand blasted, acid washed or similar) to all horizontal or low sloped surfaces where snow or ice could collect.

4.0 Mock-up Performance Testing

Various Tapestry Samples were installed in the cold room laboratory of the Ice Engineering Facility at the Cold Regions Research and Engineering Laboratory (CRREL), in Hanover New Hampshire, to conduct Mock-up Performance Tests. In the same laboratory during testing, next to the Tapestry Samples, various other architectural mesh or screen samples and study screen samples, with varied cable placements, were also installed to serve as comparison to the Tapestry Samples. A further 12" x 12" stone sample was also investigated, as previously mention. Overall, seventeen (17) individual tests were conducted on the Tapestry Samples.

The Mock-up Performance Testing exposed the Tapestry Samples to; moderate sticky snowfall, wet wind driven snowfall, icy sleet/snow, and freezing rain, simulating winter events in Washington DC. The initial iteration of testing also investigated rainfall and wind driven rain. The iterative approach to testing resulted in a greater understanding of the relationship between the various aspects of Tapestry Art Work, Tapestry Base Assembly, and the overall support structure resulting in estimates of potential for ice or snow formation. Consequently, it is important to note that initial investigations and testing lead to modifications that were incorporated into revised versions of Tapestry Samples for the each subsequent iteration of testing. The resultant guidelines and recommendations that were developed are provided in section 4.2 below.

4.1 Mock-up Performance Test Plan

Prior to each iteration of testing, careful thought was given to the winter weather scenarios and their order of testing. Test plans were arranged to begin with the more common snow scenarios, working towards the larger less frequent combinations, then onto ice formations from freezing rain. Time was also allotted for the duplication of tests, repeating the most influential results and comparisons to architectural samples and additional sample screens (as discussed previously), to allow for further validation and confidence in the results.

4.2 Influencing Factors, Findings and Recommendations

The following summarizes the influencing factors, findings, and subsequent guidelines and recommendations developed during the Mock-up Performance Tests:

1. *Tapestry Base Assembly* – The Tapestry Base Assembly is comprised of vertical and horizontal welded cables that create the support structure for the Tapestry Art Work that makes-up the various scenes. The cold room investigations identified that the spacing relationships between the vertical and horizontal Tapestry Base Assembly cables were important to the collection and subsequent release mechanisms of ice and snow.

   Specifically, it was found that a double row or pair of horizontal cables (i.e., one cable mounted on each face of the vertical cables with 3/8” spacing between, shown in Figure 1 below), provided additional attachment of accumulated snow, promoting the snow to melt away in place, releasing as smaller or individual and much softer, less dense or slushy snow formations. Subsequent iterations of testing validated the alternating aspect of the paired cables (i.e., pairs alternate front and back then back and front, see Figure 1 below), establishing a Base Tapestry Assembly with equivalent performance on either face.

   Regarding the spacing between horizontal cable pairs of the Tapestry Base Assembly (i.e. 1-1/8” spacing, shown in Figure 1 below), this dimension generally correlated to the size of individual pieces that would release at the end of the melt out period. Earlier iterations tested various spacing dimensions ranging from 9” to 1-1/8”. It was found that the larger horizontal spacing between cable pairs did not provide adequate attachment to hold and separate larger snow accumulations, formed from moderately heavy to severe winter storms. In contrast, the smallest spacing of 1-1/8" held accumulated snow for a significant portion of the melting period and released slushy snow in small sections or rows of sections. Freezing rain or ice storms accumulations performed similarly for all dimensions as the ice forms directly on cable segments and tend to release as small and individual pieces at the end of the melting period.

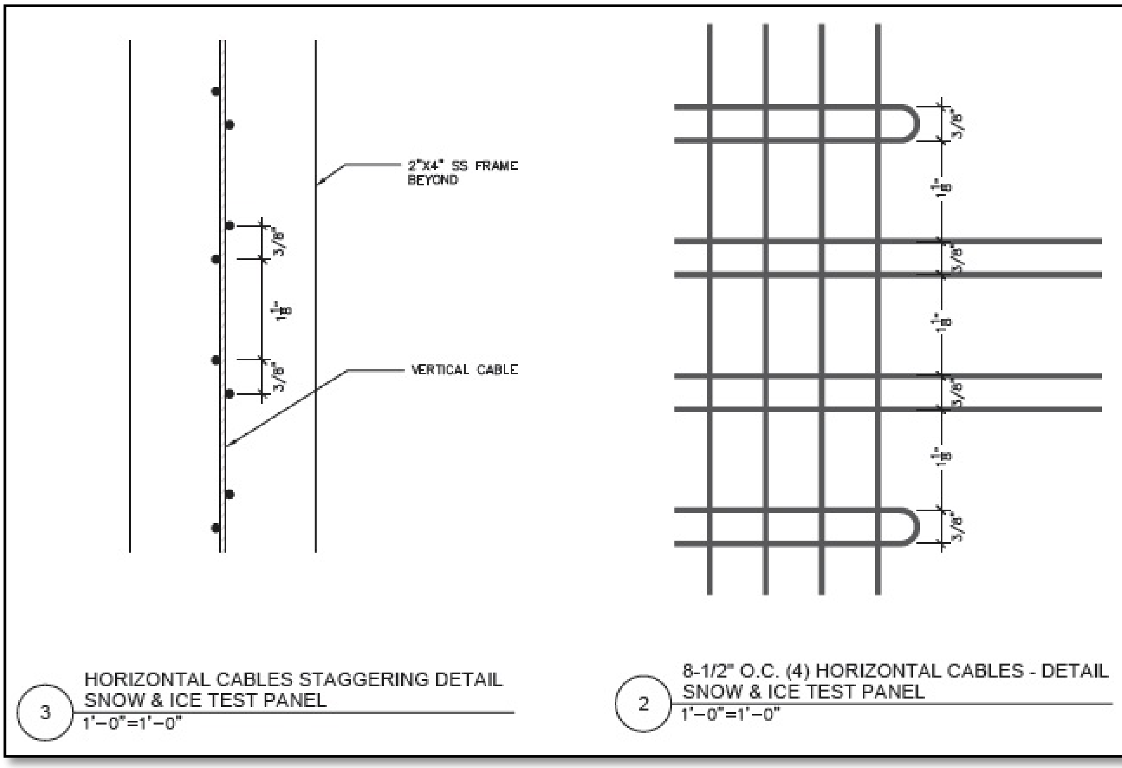


Figure 1: Recommended configuration of Tapestry Base Assembly

Therefore, the dimensional format of the Tapestry Base Assembly shown in the Figure 1 is recommended as the maximum dimension for the final design.

2. *Tapestry Art Work* – The scenes of the tapestry are comprised of Tapestry Art Work which is constructed of various sized braided cables welded in various densities and patterns, to both sides of the Tapestry Base Assembly. Test results found that the Art Work in general provided 3-dimensional complexity and non-uniformity (e.g., braided cables that weave together and are welded to both the front and back of the Tapestry Base Assembly in a complex pattern), resulted in improved performance over other cable samples and more traditional architectural screen or mesh samples. This improvement is attributed to the 3-dimensional complexity and non-uniformity which provided anchorage for accumulations and served to segment formations into smaller pieces that would release late in the melting period as soft or slushy snow.

   A further observation was noted in areas where the art work pattern was less dense, however angular as opposed to the base assembly grid. The less dense welded Art Work served to separate rows and provide additional anchorage to the accumulated snow or ice formations.

Therefore, the following guidelines are recommended for the final design:

- The application of Tapestry Art Work on both sides, divided as evenly as possible between sides of the Tapestry Base Assembly, is an important feature and should be maintained within the final design;
- The application of some form of angular or non-uniform art work scenery should be considered in all areas of the Tapestry Base Assembly (both sides), thereby avoiding open sections of base assembly and providing additional anchorage and release points for accumulated snow; and,
- Consideration to the layout of the Tapestry Art Work over areas where walkways exist below, providing scenes that fill the tapestry panels above walkways with 3-dimensional complexity and non-uniformity.

3. *Bottom Tension Cable of the Tapestry Base Assembly* - The tension cable situated at the bottom of the tapestry is shown to be wrapped by the vertical cables of the base assembly, connecting the Tapestry Base Assembly to the support frame (Figure 2). The wrapping of the vertical cables around the bottom tension cable's radius provides a 3-dimensional complexity (similar as noted above), which is a positive design feature. Thus, it is recommended that the wrapping feature of the vertical support cables be retained within the design.

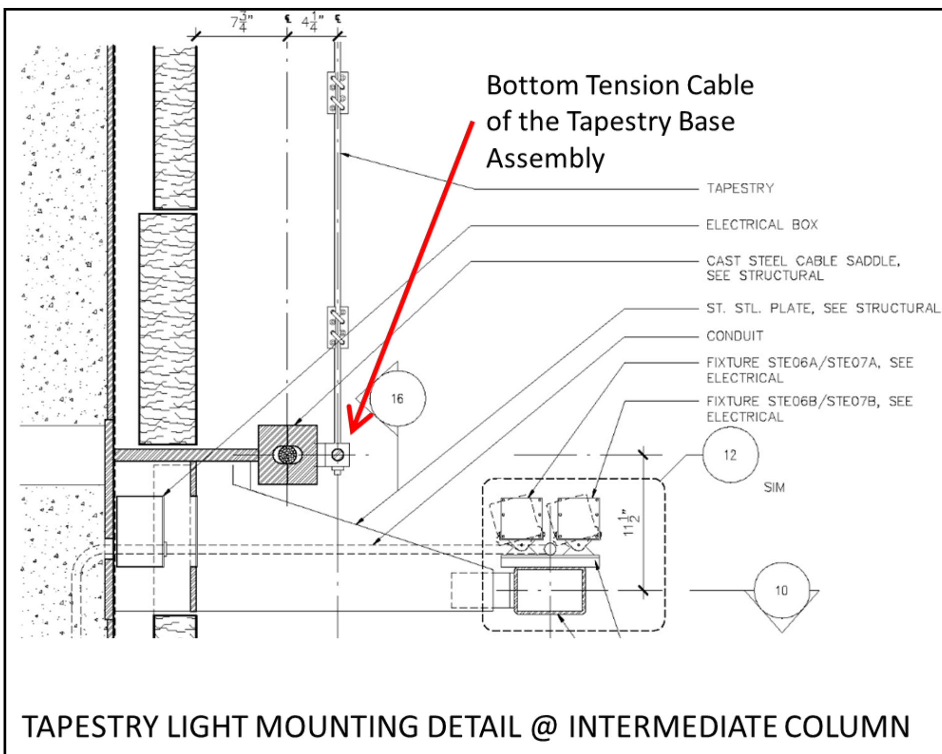


Figure 2: *Bottom Tension Cable of the Tapestry Base Assembly*

4. *Side Supports of the Tapestry Base Assembly* –It is recommended that the side support connections of the final Tapestry Base Assembly be minimized in size and complexity, and oriented in a vertical axis to further reduce horizontal dimensions that can collect ice or snow.

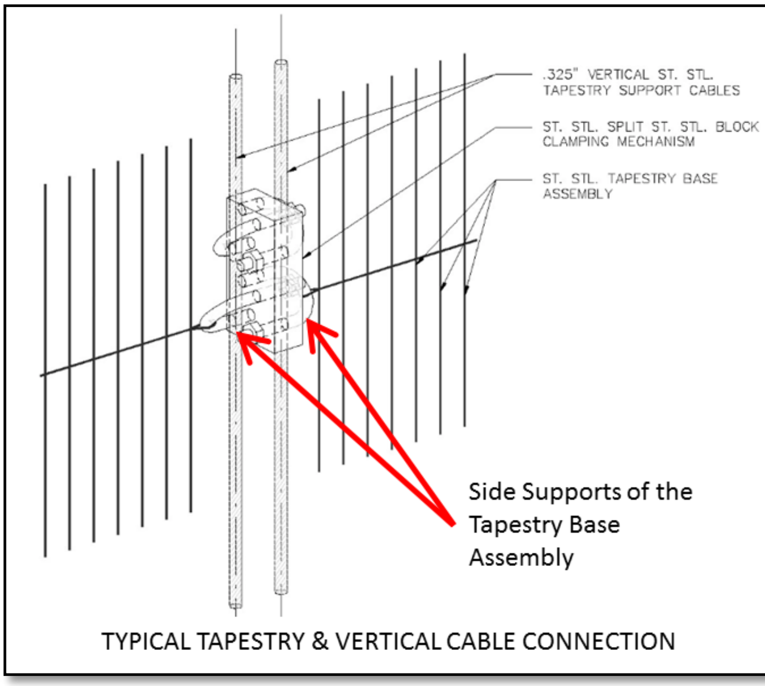


Figure 3: Side Supports of the Tapestry Base Assembly

5. *Rain and Melt Water Migration* – The Proof of Concept Aesthetic Mock-up was subjected to rain simulations to assess drip patterns, in addition to observations of dripping melt water during ice and snow tests. It was found that a controlled release of dripping rain or melt water occurs from the base of the tapestry with Art Work present, even during heavy rain events. This suggests that, in the absence of high winds, the drip pattern from the full tapestry with art work should consist of a straight narrow line directly below the bottom tension cable where a drainage grill exists. It is recommended that the final design include under pavement heating that extends a minimum of 15' either side of the trench drains provided on grade at the center line of the tapestry, anywhere that tapestry exists above a pedestrian assessable walking surface. The heated portions of walkway should slope towards or have a drainage path to the trench drains, and cover the entire width of each walking surface, providing an automated approach to the melt of snow accumulation or slippery walking surfaces.

6. *Stone Surfaces* – The test results revealed that the flamed surface finish of the stone could still allow some movement of melting ice and snow, thus a rough surface texture (e.g., sand blasted, acid washed or similar) is recommended to be specified for the top of stone surfaces where ice and snow can collect.

6.0 Applicability of Results

The following statements cover various aspects of the application and interpretation of the presented results:

- Snow created in a cold room laboratory resembles wet sticky snow that is not fully developed into snowflakes. Natural snowfall typically consists of snow that is fully developed and less sticky due to open exposure and the fall from higher elevations. Thus, the results from the cold room test method should be interpreted as conservative for typical snowfall conditions, and best resembles less frequently occurring wind driven sleet or transitional snowfall that exists for shorter periods of time in storm events.

- The recommendations and design guidelines provided have been developed to anticipate both typical winter weather and the influence of strong wind gusts, unusual conditions, or extreme storm events. However, it is important to recognize that the occurrence of adverse conditions, which effect all buildings and structures in general, can never be completely eliminated. Therefore, as with any building or structure assessed by Northern Microclimate, it is recommended that a Winter Operational Protocol be developed, tailoring winter operational procedures to the specific performance characteristics of the completed project site.

- To ensure that the recommendations and guidelines described within this report are interpreted and incorporated as intended into the final design documents. It is recommended that the details of the final design be reviewed by Northern Microclimate to determine if further investigation or guidance is necessary.

5.0 Conclusion

The investigative and iterative approach to refinement of all aspects of the project site, including the Tapestry Base Assembly and the application of Art Work as the finished Tapestry, has resulted in design modifications, guidelines, and recommendations that will significantly reduce the potential for winter performance issues. Furthermore, the results of the Mock-Up Performance tests document a positive correlation between the Tapestry Samples tested and samples of architectural screen or mesh samples that are commonly used in the building industry, and have not been reported to be problematic. Finally, it is important to note that in areas of Art Work, the tapestry performed better in aspects of snow formation and release characteristics than the architectural samples.

Consequently, it is our opinion that the implementation of the recommendations and guidelines contained within this report, including those within Appendix A, will significantly reduce the potential for winter performance issues.

7.0 Appendices

Appendix A – Meteorological Analysis and Ice and Snow Consultation

Appendix A

Meteorological Analysis and Ice and Snow Consultation

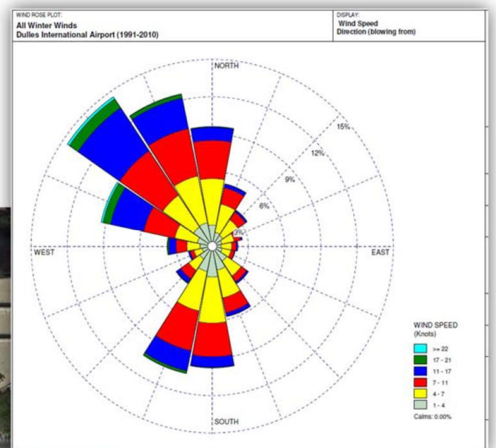
DWIGHT D. EISENHOWER MEMORIAL

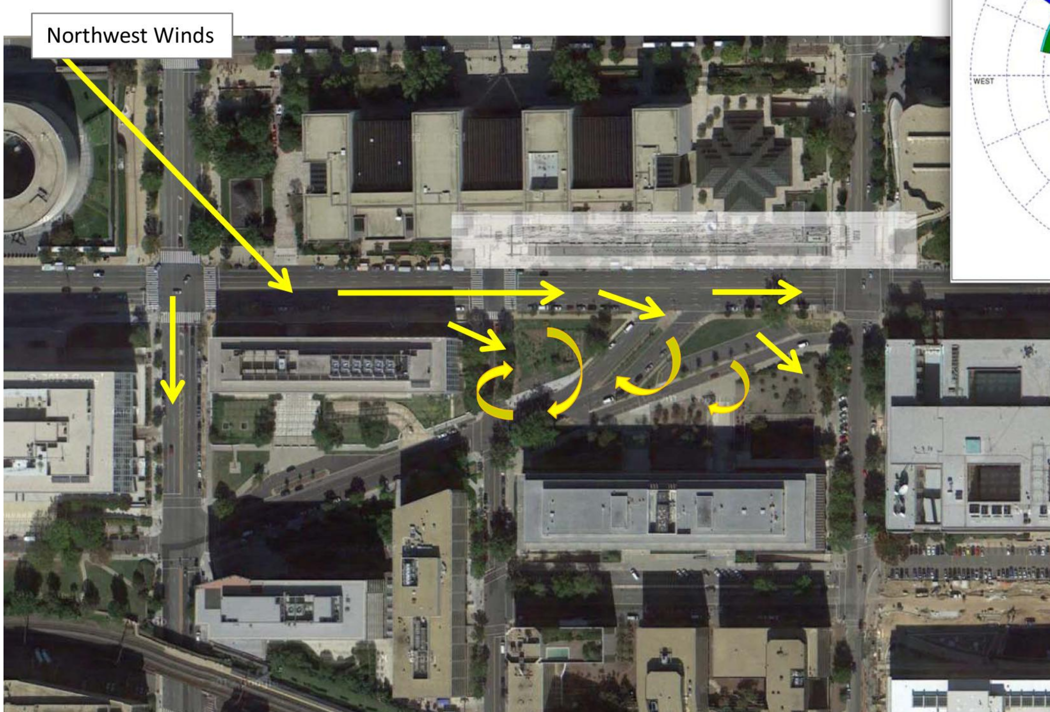
northern MICROCLIMATE

Discussion Points:

1. **Northwesterly winds occur** the greatest percentage of the time, with the highest speeds.
2. South-southwest is a secondary wind direction during winter months.
3. Surrounding buildings provide some protection for winds from the northwest, however the west side of the site will see strong wind flows while the mid and east side of the site will experience more turbulent gusty winds.

ALL WINTER WINDS

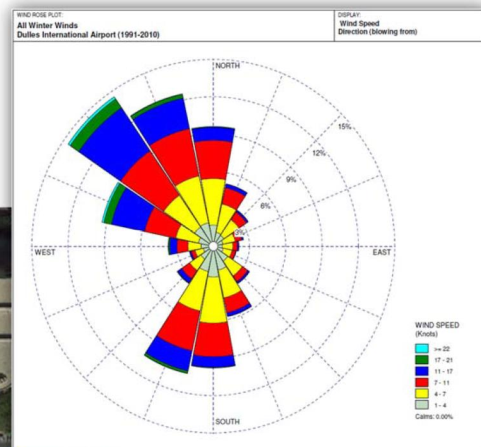


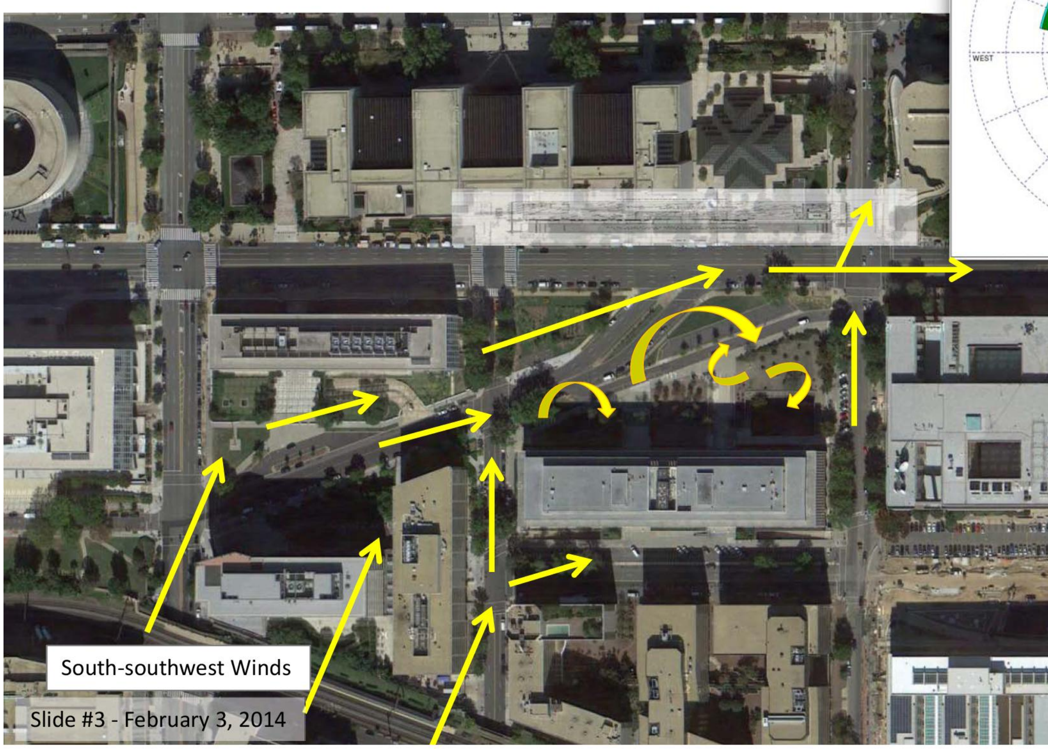


Discussion Points:

4. **South-southwest winds** will also impact the west side of the site and produce more turbulent gusty winds across the remainder of the site.

ALL WINTER WINDS



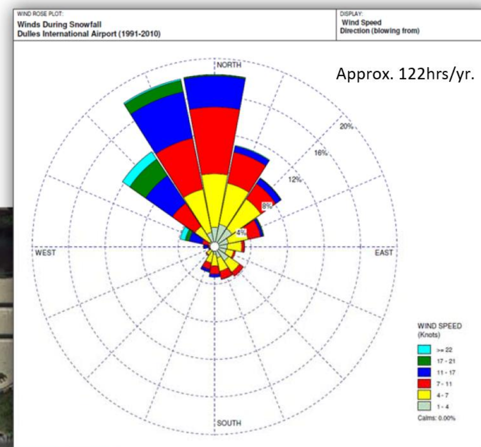


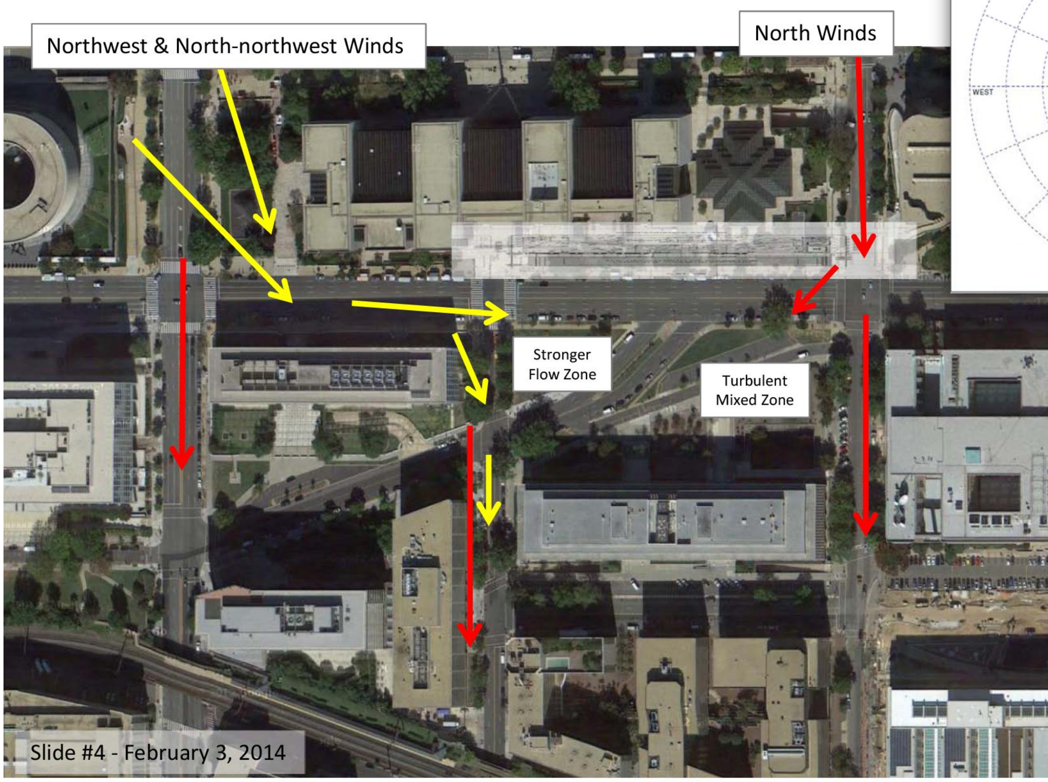
northern MICROCLIMATE

Discussion Points:

1. Winds during snowfall primarily come from the **Northwest through North to the Northeast**.
2. Very little **wind with snow** comes from the southerly directions.
3. **Highest wind speeds** come from the northwest during snowfall.
4. The back of the west screen will likely experience greater wind driven snow events, while the fronts of the south screens will experience a moderate number of events. The front of the east screen will likely experience similar or slightly greater events than the south screens.

Winds During Snowfall

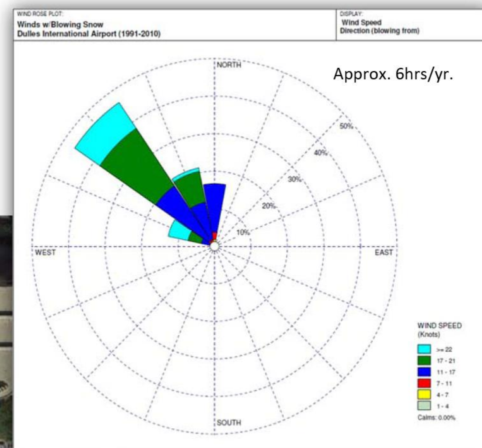


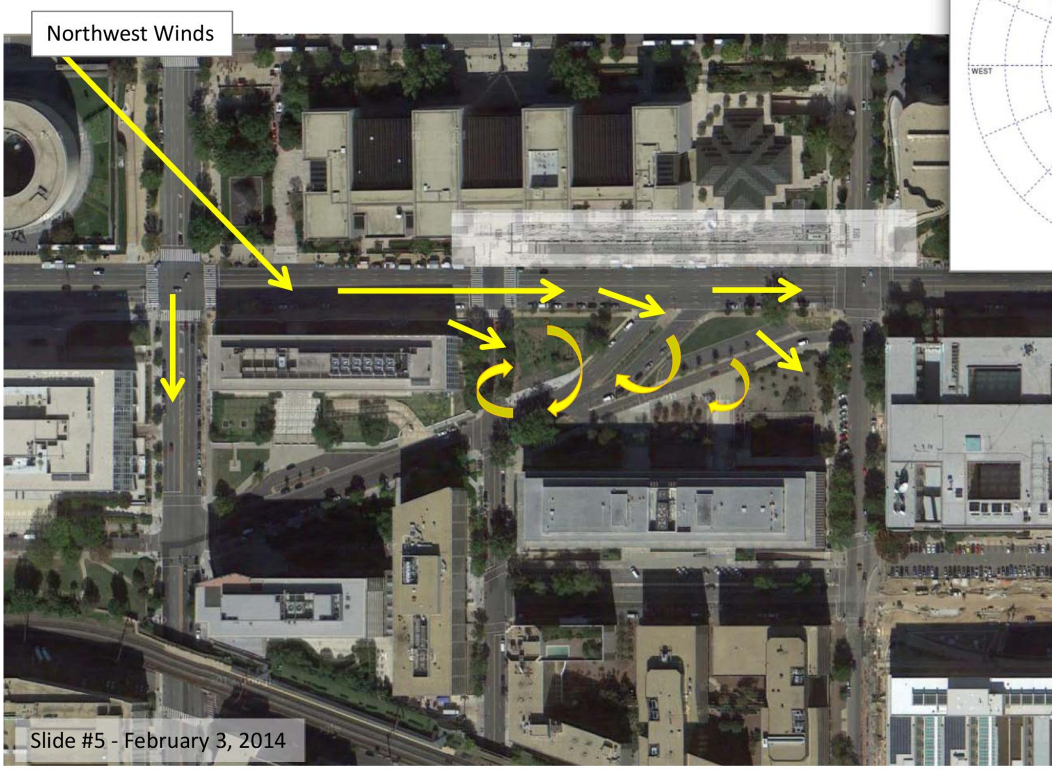


Discussion Points:

1. Winds during **blowing snow** primarily come from the west-northwest, **Northwest** and north-northwest.
2. **Highest wind speeds** come from the west-northwest and **Northwest** directions.
3. Blowing snow occurs approximately **6 hours a year** on average.
4. This will have the greatest influence on the back of the west screen.

Winds with Blowing Snow



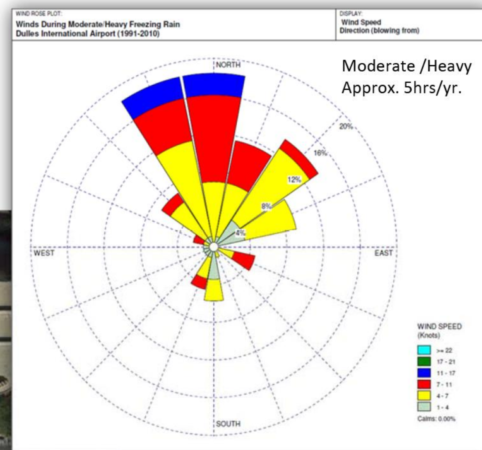


northern MICROCLIMATE

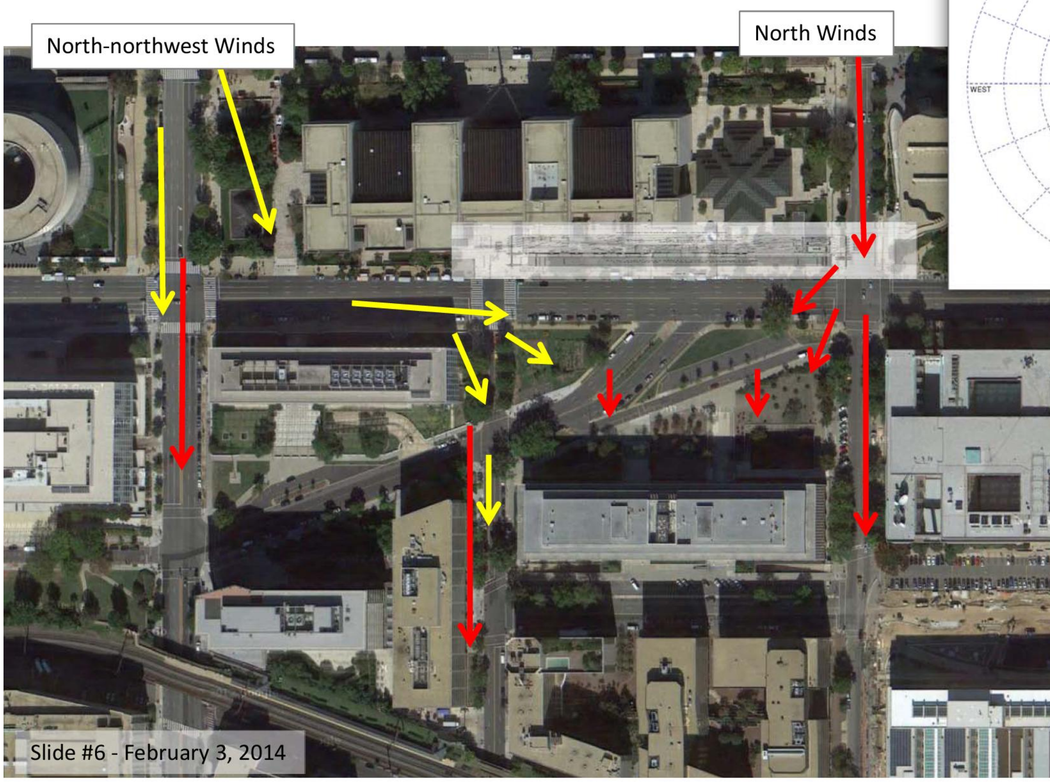
Discussion Points:

1. Winds during freezing rain primarily come from the **North-northwest and North**.
2. Wind speeds are **low to moderate** during freezing rain events.
3. Collection on all screens is possible with the greatest potential for formations on the front faces of the south screens.

WINDS DURING FREEZING RAIN



All Freezing Rain
Approx. 32hrs/yr.



Slide #6 - February 3, 2014

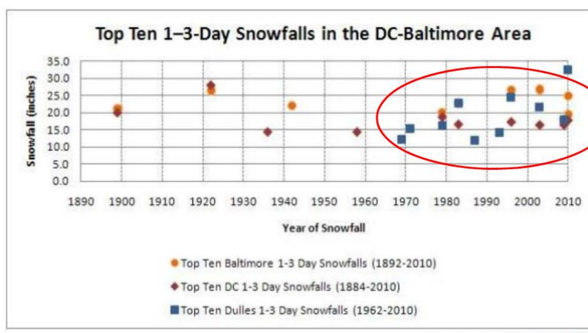
OVERALL WINTER STATISTICS

	Dulles Int'l Airport	Ronald Reagan Washington National Airport
Average Seasonal Snowfall	22.8 inches	16.6 inches
Greatest Number of Consecutive Days with an inch or more of snow on the ground		Nov. = 4 days – 1938 Dec. = 20 days – 1989 Jan. = 21 days – 1893 Feb. = 26 days – 1905 Mar. = 12 days - 1960
Snowiest Season	73.2 inches – 2009-2010	56.1 inches – 2009-2010
Top Snowfall in 3 day Period	32.4 inches – Feb 5-6, 2010	28 inches – 1922

1. The Washington D.C. climate shows snow depth variation between Dulles Int'l and Ronald Reagan National Airport.
2. The timeframe between occurrences of severe winter storms is shortening. Thus, severe storms are becoming more common.
3. Annually, Washington receives 5 days/year with 1" or greater of snowfall, and a 10" snowfall 1 in 5 years on average.

It is therefore proposed that the project design anticipate storm events with snowfalls up to 8 or 10 inches in depth; and, address more severe (less frequent) events with the added contribution of operational procedures and maintenance.

Daily Frequency of Snowfall (in Days Per Year)			
	DC	Baltimore	Dulles
≥ 1"	5.4	5.8	5.9
≥ 2"	3.3	3.8	3.9
≥ 4"	1.4	1.7	2.0
≥ 6"	0.6 (3 in 5 years)	0.8 (4 in 5 years)	0.9 (9 in 10 years)
≥ 8"	0.3 (3 in 10 years)	0.4 (2 in 5 years)	0.4 (2 in 5 years)
≥ 10"	0.2 (1 in 5 years)	0.2 (1 in 5 years)	0.3 (3 in 10 years)

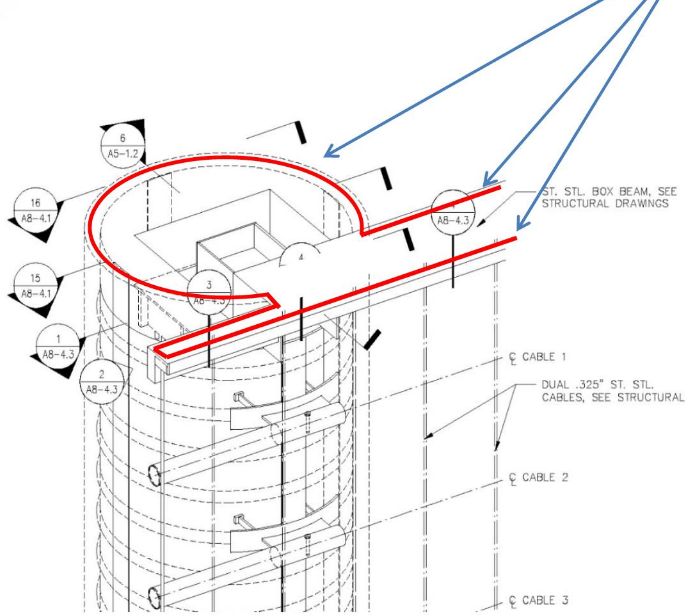


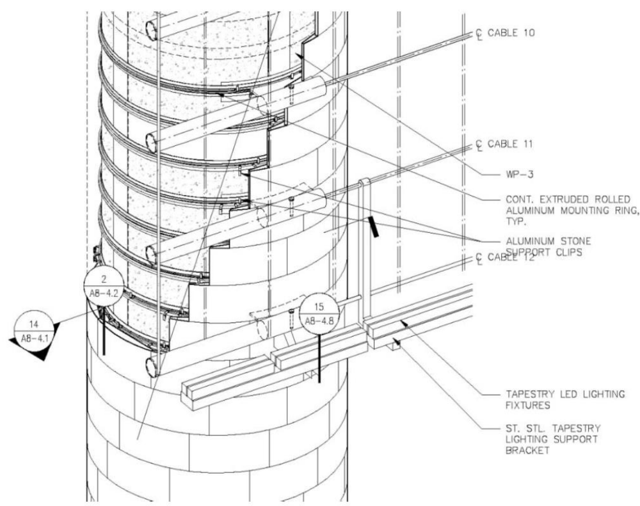
* Statistics gathered from NOAA/National Weather Service and the National Environmental Satellite, Data, and Information Service (NESDIS) web resources.

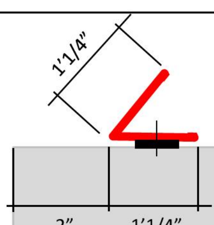
Columns & Support Structure

1. Ice and snow retention for the Box Beam as well as the Column Top is recommended.

Perimeter Barrier



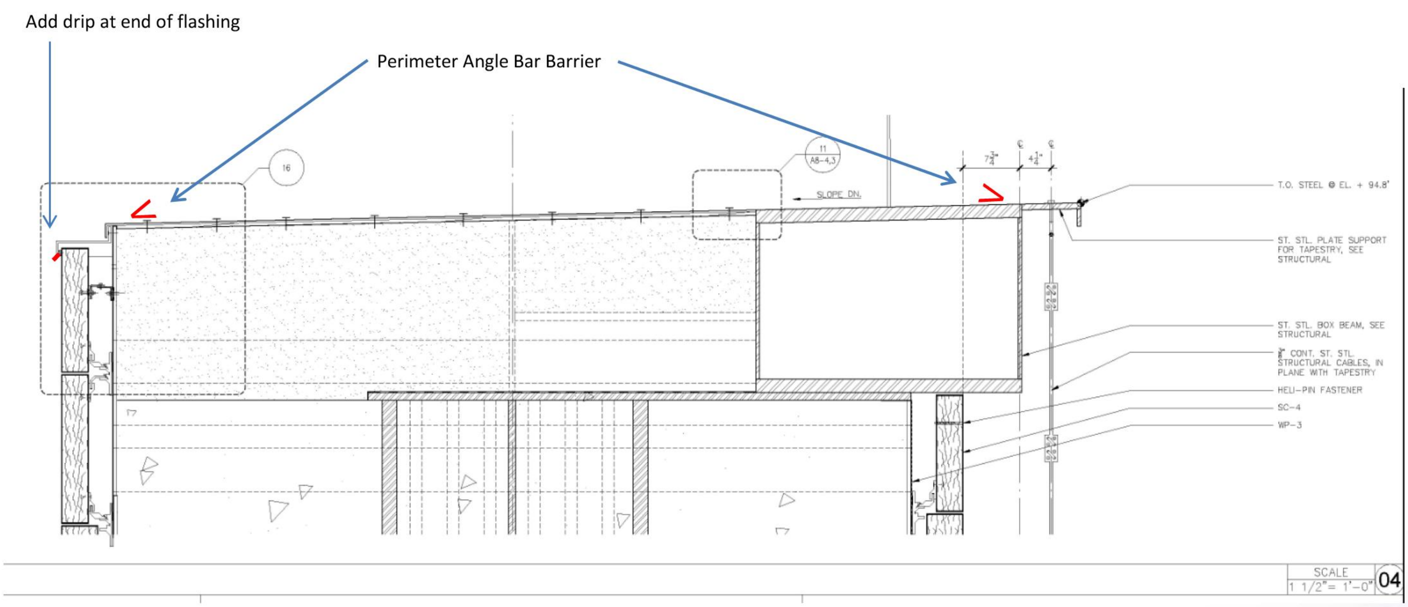




Angled Bar Barrier - 45° Bent angle bar with each leg 1-1/4" anchored 2" back from leading edge of surface. Bar Barrier mechanically fastened with 3/16" spacer at each fasteners.

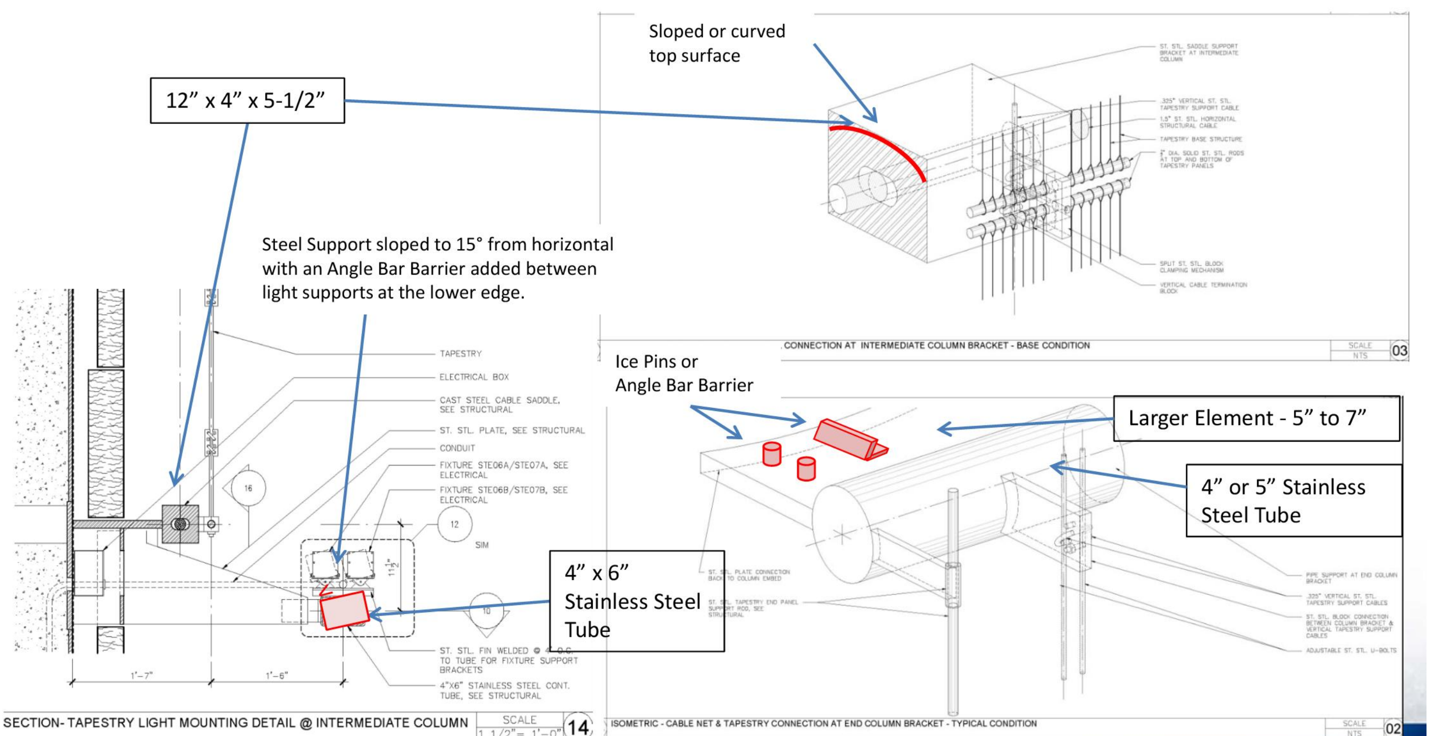
Columns & Support Structure

1. A perimeter barrier is recommended for the top of columns.
2. The addition of a drip to the flashing can reduce icicle potential and also protect the stone below from staining.



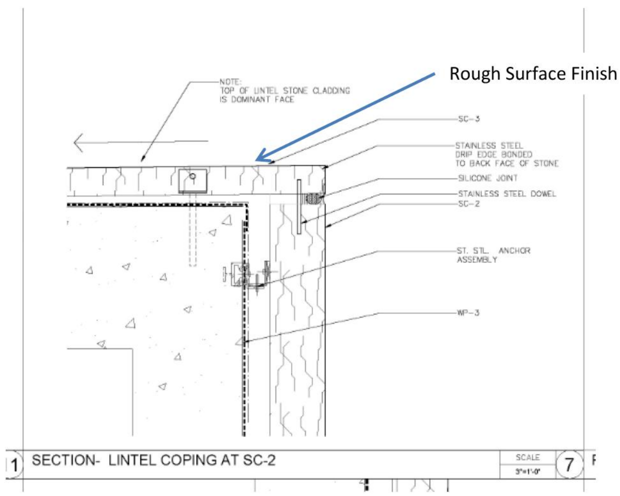
Tapestry Support Structure

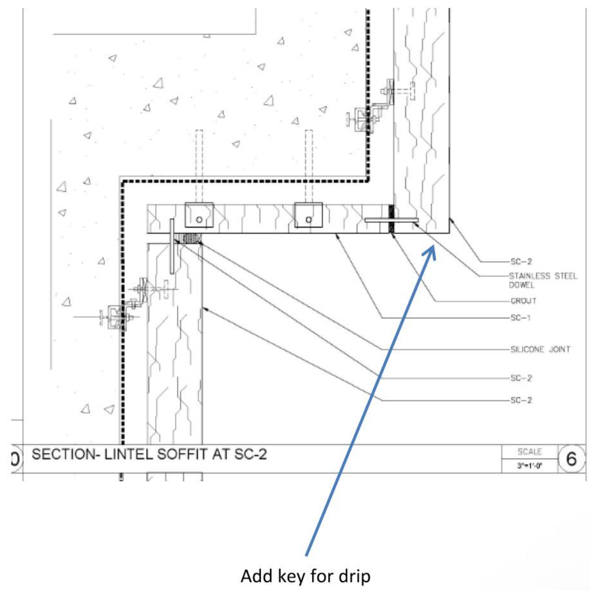
1. As a guideline, it is recommended that the overall size and horizontal top surfaces of support elements (shown below) be sloped, curved or reduced in size, and/or their orientation configured in the vertical axis over horizontal. For larger elements, Ice Pins or Angle Bar Barriers can be used to retain ice and snow.
2. It is recommended that the top surface of the light support (4" x 6" stainless steel tube) consist of a sloped surface (15° from horizontal) and contain a raised Angle Bar Barrier between light supports at the lower edge (shown below).



Memorial Block and other Stone Surfaces

1. Stone surfaces can perform as slippery or rough depending on the porosity and roughness of the surface. Thus, it is recommended that the top surface of the Memorial Block, along with other stone parapets, sills and top surfaces, be specified as rough surfaces (e.g., sand blasted finish, acid washed, etc.).
2. A drip key or edge details used to promote water to leave the stone surface is recommended in areas of a soffit or undercut.





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6.0 MAINTENANCE AND CLEANING

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6.1 STAINLESS STEEL CLEANING PROCEDURE

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6.1 STAINLESS STEEL CLEANING PROCEDURE

A. Introduction

Stainless steel needs to be periodically cleaned to maintain and preserve its corrosive resistance qualities. The corrosive resistance of stainless steel is due to a process called “self-passivation.” Stainless steel surfaces thrive with periodic cleaning because there is no coating to wear off. The frequency and cost of this cleaning is lower than many of the other noble metals. For this Memorial, the selection and use of 316L structural stainless steel components and 317L stainless steel for the tapestry panels will not corrode under normal atmospheric conditions and if a periodic maintenance plan is implemented.
Attached to this report is ASTM A380-06 Standard Practices for Cleaning, Descaling and Passivation of Stainless Steel Parts, Equipment and Systems. This standard further describes recommendations for cleaning, descaling and passivating of new stainless steel parts, assemblies, equipment and installed systems applicable to the memorial design.

B. Recommendations for protection after fabrication, shipping and initial cleaning of stainless steel tapestry

Upon completion of fabrication for each tapestry panel, a non-adhesive protective plastic film or other means of temporary protection will be supplied by the fabricator. The fabricator will be responsible for wrapping and protecting the stainless steel panels from damage and soiling after fabrication, storage and shipment. Once the installation of the tapestry panels is complete, the removal of the protective film should be done from top of the tapestry down. Once the protective film is removed the initial cleaning should consist of the following steps (always working from top to bottom):

Initial General Cleaning (after installation)

1. Rinse with potable water to remove dirt. This should be done with a low pressure washer.
2. Wash with warm water containing soap, detergent or 5% ammonia using a soft long synthetic fiber brush.
3. Rinse with clean potable water. (the area can be rinsed with potable water to dilute the detergent so as not to harm the landscaping)

Contamination of Stainless Steel with iron particles when contact with tools or carbon steel

1 Mild staining or surface bloom should be removed with the use of a non-abrasive calcium carbonate cream or other approved method.
2. Fresh steel grindings or dust may be removed by a saturated solution of oxalic acid applied with a soft cloth or synthetic bristle brush.

3. Moderate rust staining can be removed by the application of phosphoric acid. (the treated area can be rinsed with potable water to dilute the solution so as not to harm the landscaping).
4. Severe rust stains can be addressed by applying new localized passivation of the existing surface once the contaminant has been removed.

C. Periodic Maintenance Program for Stainless Steel Tapestry

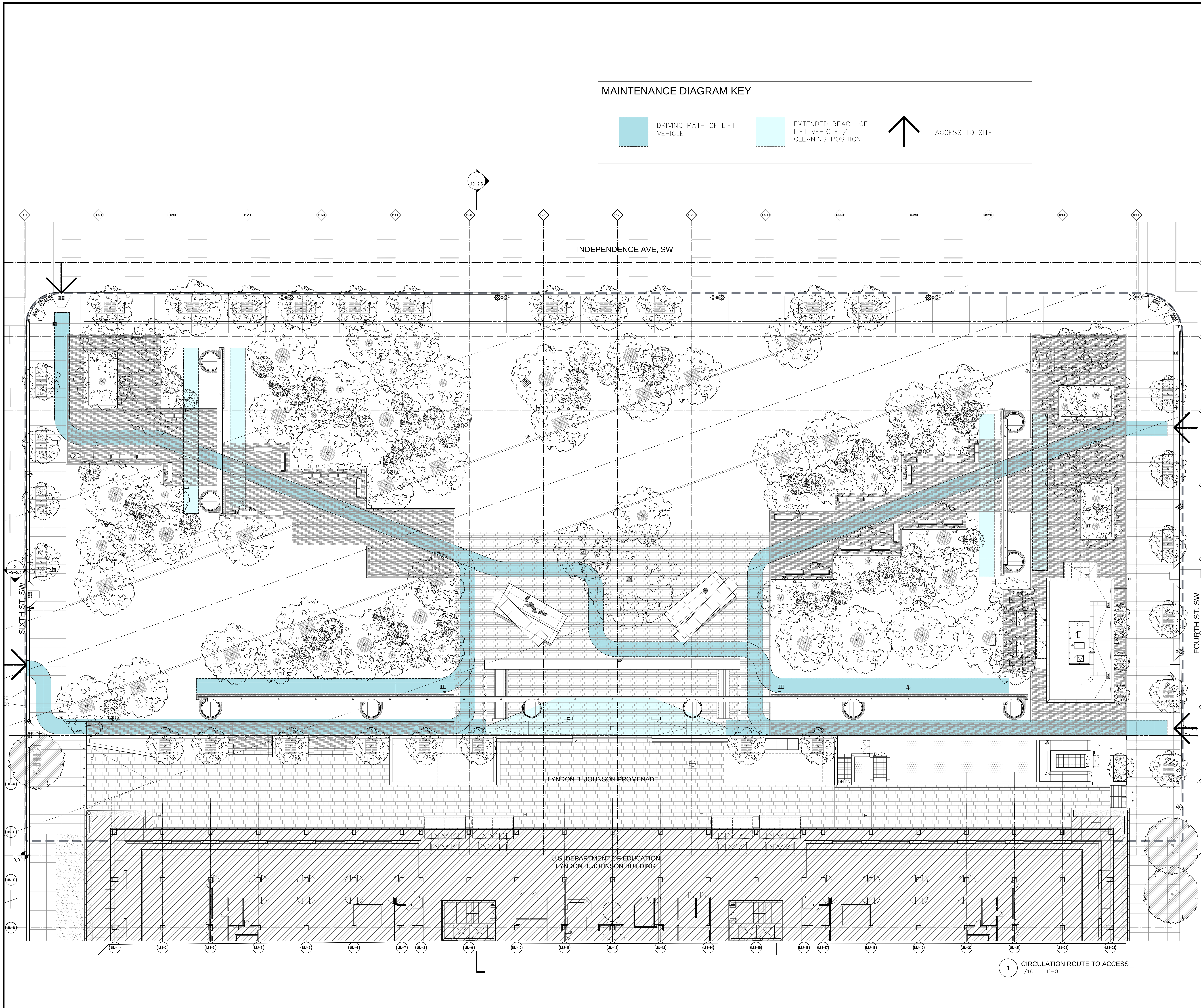
Although Stainless steel has high levels of intrinsic corrosion resistance, there can be isolated cases of tea staining caused by the lack of or improper cleaning of the material. Incorrect or aggressive cleaners, de-icing salts and acid rain are common causes for such tea staining and can be mitigated by the introduction of a good maintenance and cleaning program. The cleaning of the stainless steel tapestry is no different to other building materials. Cleaning should be performed before there is visible buildup on the tapestry, this will ensure that the effort and cost of cleaning is minimal.

Stainless steel is easy to clean. As in the initial cleaning recommendation, the tapestry can be routinely cleaned by washing it with soap or a mild detergent a synthetic brush and warm water followed by a clean potable water rinse. This method is quite adequate for the general cleaning of the tapestry.

It is recommended that the tapestry undergo this simple wash-down on a yearly basis.

The annual washing will require one man lift. The project has been designed with clearances for the lifts in mind as shown in the designated pathways on drawing A9-2.2. Two potential lift products have been identified with the required reach for servicing the tapestries: the JLG 860 SJ lift, and Manlift Manufacturing Company A73TDI Electronically Insulated Track Drive Lift. The two lifts are shown in section on A9-2.3 to demonstrate the equipment reach works for the tapestry height. The pavement design and landscape areas have been designed to accommodate this equipment. The project costs include the purchase of one lift for ongoing NPS maintenance on the site. The lift will be stored off site.

A detailed maintenance program for periodic cleaning of the tapestry will be established at the time of the Performance Mock up.



1 CIRCULATION ROUTE TO ACCESS
1/16" = 1'-0"

GSA GENERAL SERVICES ADMINISTRATION
301 7th STREET S.W.
WASHINGTON, DC
20407-0001

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CERTIFICATIONS

KEY PLAN

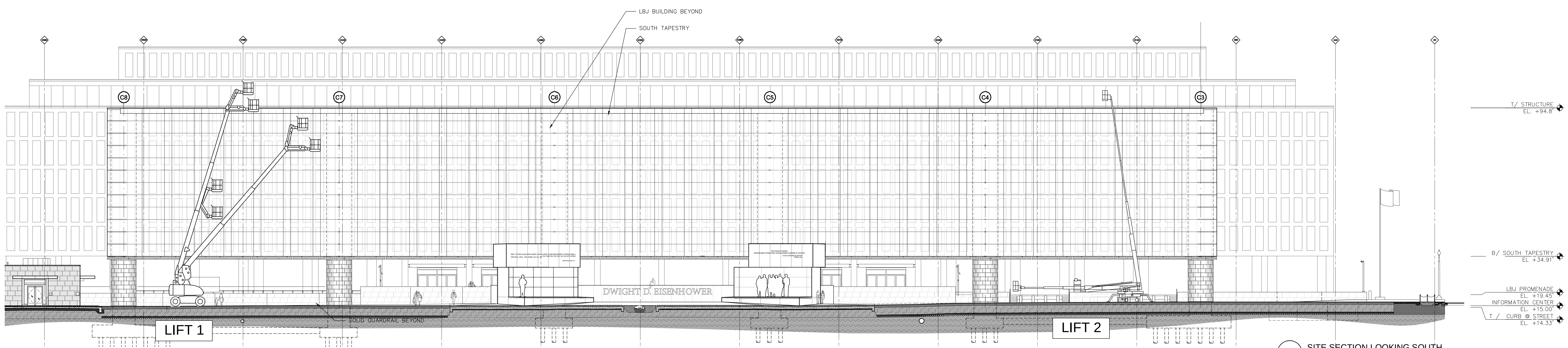
MARK	DATE	DESCRIPTION

REVISION NOTES

GRAPHIC SCALE 0' 16' 24' 32'

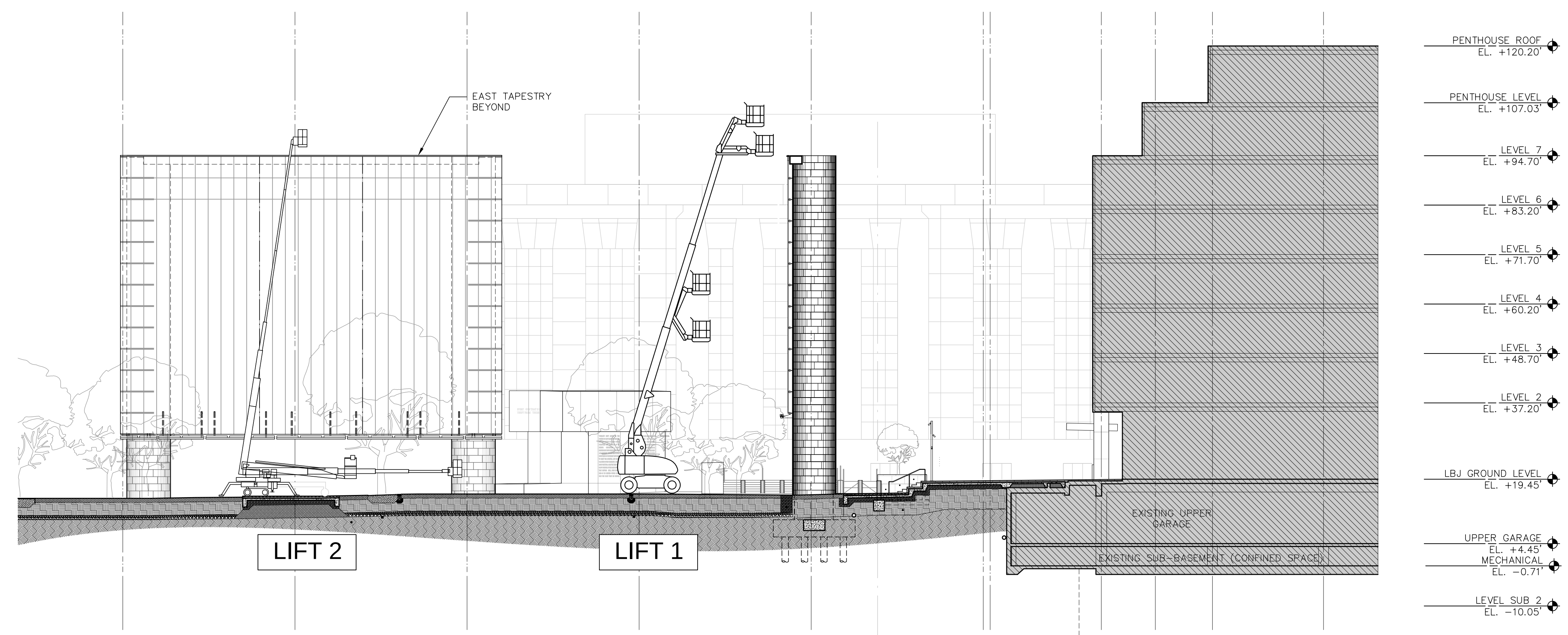
A/E CON. NO.	GS-11P-10-MK-C-0038
A/E TASK NO.	
CONS. CONTR.	
CONS. WORK	
PRIME A/E	Gehry Partners • AECOM Joint Venture
SUB A/E	
CONSTR. CON.	GS-11P12MKC0005
NAME	DWIGHT D. EISENHOWER MEMORIAL
STREET	545 INDEPENDENCE AVENUE, SW
CITY/ST/ZIP	WASHINGTON, DC 20024
BUILDING NO.	
OTHER BUILDING NOs.	
FACILITY CODE	
PROJECT TITLE	DWIGHT D. EISENHOWER MEMORIAL
PROJECT DESCRIPTION	DWIGHT D. EISENHOWER MEMORIAL
PROJECT NO.	NDC07001
GSA PM	-
SUBMISSION	100% CONSTRUCTION DOCUMENTS
SUB. DATE	12/17/2012
DRAWING TITLE	SITE MAINTENANCE DIAGRAM - PLAN
FILE NAME	A9_2-2-NDC07001
FLOOR NO.	-
DRAWN BY	MF DATE DRAFTED: 01/28/2014
CHECKED BY	SK SHEET SIZE: 36X48
DRAWING NO.	A9-2.2-NDC07001

DISCIPLINE SHEET TYPE SEQUENCE
SHEET OF



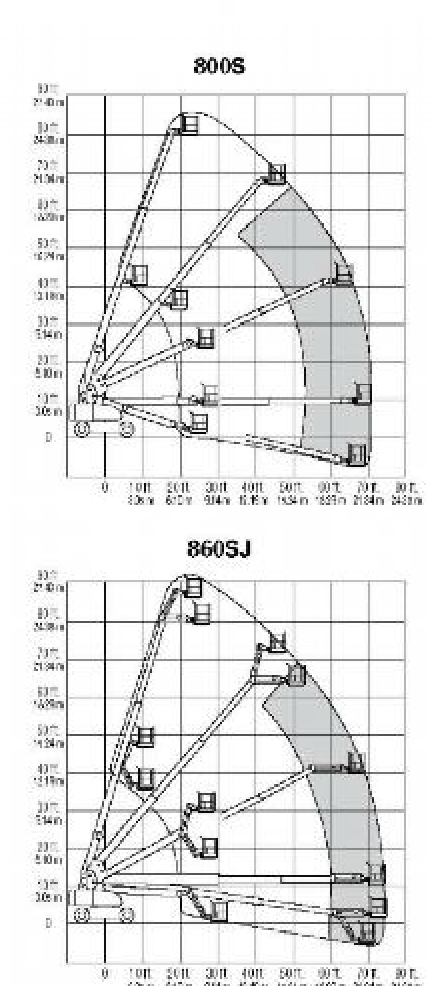
2 SITE SECTION LOOKING SOUTH
1/16" = 1'-0"

LIFTS SHOWN FOR EXTENT OF REACH



1 SITE SECTION @ TERRACES LOOKING EAST
1/16" = 1'-0"

BASIS OF DESIGN - LIFT 1
LIFT TO BE STORED OFFSITE



Specifications

800S

860SJ

Reach

Platform Height	
800S	80 ft (24.38 m)
860SJ	86 ft (26.21 m)
Horizontal Outreach	
800S	71 ft (21.64 m)
860SJ	75 ft (22.86 m)
Swing	360° Continuous
Platform Capacity—	
Restricted [800S]	1,000 lb (454 kg)
Restricted [860SJ]	750 lb (340 kg)
Platform Capacity—	
Unrestricted	500 lb (227 kg)
Platform Rotator	180° Hydraulic
Jib Range of Articulation	
860SJ	130° (+70, -60)

Dimensions

A. Platform Size	36 x 96 in. (0.91 x 2.44 m)
B. Overall Width	8 ft 2 in. (2.49 m)
C. Tailswing (working condition)	4 ft 8 in. (1.42 m)
D. Stowed Height	
800S	9 ft 11 in. (3.02 m)
860SJ	10 ft (3.05 m)
E. Stowed Length	
800S	37 ft 3 in. (11.35 m)
860SJ	40 ft (12.19 m)
F. Wheelbase	10 ft (3.05 m)
G. Ground Clearance	12 in. (30 cm)
Weight[1]	
800S	33,200 lb (15,060 kg)
860SJ	36,400 lb (16,511 kg)
Max. Ground Bearing Pressure	
800S	72 psi (5.06 kg/cm²)
860SJ	81 psi (5.69 kg/cm²)

Chassis

Drive Speed 2WD	3.5 mph (5.6 km/h)
Drive Speed 4WD	3.5 mph (5.6 km/h)
Gradeability 2WD	30%
Gradeability 4WD	45%
Tires	15.625 Pneumatic
Turning Radius	
Inside	12 ft (3.66 m)
Outside	22 ft 6 in. (6.86 m)

1. Certain options or country standards increase weight.

Power Source

Dual Fuel Engine, GM Vortec 3000 MPFI	82 hp (61 kW)
Diesel Engine, Deutz D2011L04 with EGR	64 hp (47 kW)
Diesel Engine, Caterpillar C3.4	63.3 hp (47.2 kW)
Fuel Tank Capacity	31 gal (117.3 L)
Hydraulic Reservoir	48 gal (181.7 L)
Auxiliary Power	12V DC

800S

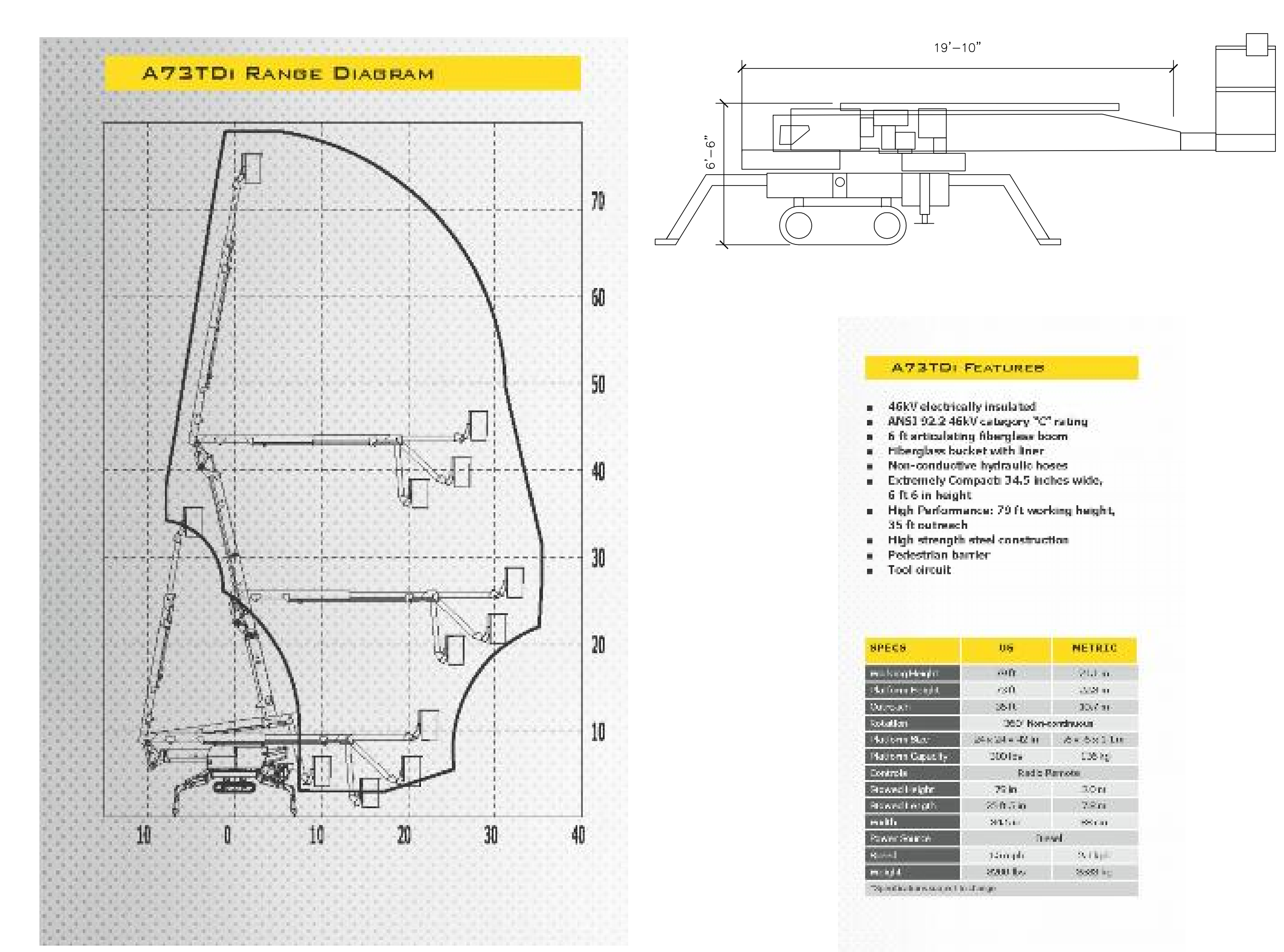
800SJ

The JLG "1 & 5" Warranty

JLG Industries, Inc. backs its products with its exclusive "1 & 5" Warranty. We provide coverage on all products for one (1) full year, and cover all specified major structural components for five (5) years. Due to continuous product improvements, we reserve the right to make specification and/or equipment changes without prior notification. This machine meets or exceeds applicable CSA Regulations in 29 CFR 1910.07, 29 CFR 1926.453, ANSI A92.6-2006, and CSA Standard CAN3-B354.2-M82, as originally manufactured for intended applications.

JLG 800 SERIES TELESCOPIC BOOM LIFT

ALTERNATIVE LIFT 2
LIFT TO BE STORED OFFSITE



MAN LIFT MFG - A73TDI ELECTRICALLY INSULATED TRACK DRIVE LIFT

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PROJECT

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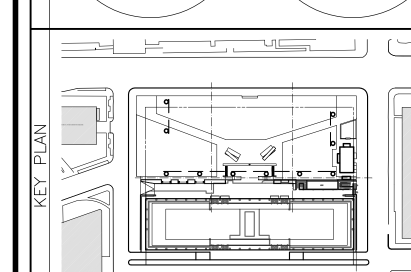
KEY PLAN



REVISION NOTES

MARK	DATE	DESCRIPTION

GRAPHIC SCALE: 0' 16' 24' 32'

CONTRACTORS	A/E CON. NO.	GS-11P-10-MK-C-0038
	A/E TASK NO.	
	CONS. CONTR.	
	CONS. WORK	
	PRIME A/E	Gehry Partners • AECOM Joint Venture
	SUB A/E	
	CONSTR. CON.	GS-11P12MKC0005
BUILDING	NAME	DWIGHT D. EISENHOWER MEMORIAL
	STREET	545 INDEPENDENCE AVENUE, SW
	CITY/ST./ZIP	WASHINGTON, DC 20024
	BUILDING NO.	
	OTHER BUILDING NOs.	
	FACILITY CODE	
PROJECT	PROJECT TITLE	DWIGHT D. EISENHOWER MEMORIAL
	PROJECT DESCRIPTION	DWIGHT D. EISENHOWER MEMORIAL
	PROJECT NO.	NDC07001
	GSA PM	–
	SUBMISSION	100% CONSTRUCTION DOCUMENTS
	SUB. DATE	12/17/2012
DRAWING	DRAWING TITLE	TAPESTRY MAINTENANCE DIAGRAM - SECTIONS
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	CHECKED BY	JB SHEET SIZE: 36X48
	DRAWING NO.	A9-2.3-NDC07001 (DISCIPLINE SHEET TYPE SEQUENCE) SHEET OF

Designation: A380 – 06

Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems[1]

This standard is issued under the fixed designation A380; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This practice covers recommendations and precautions for cleaning, descaling, and passivating of new stainless steel parts, assemblies, equipment, and installed systems. These recommendations are presented as procedures for guidance when it is recognized that for a particular service it is desired to remove surface contaminants that may impair the normal corrosion resistance, or result in the later contamination of the particular stainless steel grade, or cause product contamination. For certain exceptional applications, additional requirements which are not covered by this practice may be specified upon agreement between the manufacturer and the purchaser. Although they apply primarily to materials in the composition ranges of the austenitic, ferritic, and martensitic stainless steels, the practices described may also be useful for cleaning other metals if due consideration is given to corrosion and possible metallurgical effects.

1.1.1 The term passivation is commonly applied to several distinctly different operations or processes relating to stainless steels. In order to avoid ambiguity in the setting of requirements, it may be necessary for the purchaser to define precisely the intended meaning of passivation. Some of the various meanings associated with the term passivation that are in common usage include the following:

1.1.1.1 Passivation is the process by which a stainless steel will spontaneously form a chemically inactive surface when exposed to air or other oxygen-containing environments. It was at one time considered that an oxidizing treatment was necessary to establish this passive film, but it is now accepted that this film will form spontaneously in an oxygen-containing environment providing that the surface has been thoroughly cleaned or descaled.

1.1.1.2 Passivation is removal of exogenous iron or iron compounds from the surface of a stainless steel by means of a chemical dissolution, most typically by a treatment with an acid solution that will remove the surface contamination but will not significantly affect the stainlees steel itself. This process is described in a general way in 6.2.11 and defined precisely in 6.4 with further reference to the requirements of Annex A2 and Part II of the table on acid cleaning of steel. Unless otherwise specified, it is this definition of passivation that is taken as the meaning of a specified requirement for passivation.

1.1.1.3 Passivation is the chemical treatment of a stainless steel with a mild oxidant, such as a nitric acid solution, for the purpose of enhancing the spontaneous formation of the protective passive film. Such chemical treatment is generally not necessary for the formation of the passive film.

1.1.1.4 Passivation does not indicate the separate process of descaling as described in Section 5, although descaling may be necessary before passivation can be effective.

1.2 This practice does not cover decontamination or cleaning of equipment or systems that have been in service, nor does it cover descaling and cleaning of materials at the mill. On the other hand, some of the practices may be applicable for these purposes. While the practice provides recommendations and information concerning the use of acids and other cleaning and descaling agents, it cannot encompass detailed cleaning procedures for specific types of equipment or installations. It therefore in no way precludes the necessity for careful planning and judgment in the selection and implementation of such procedures.

1.3 These practices may be applied when free iron, oxide scale, rust, grease, oil, carbonaceous or other residual chemical films, soil, particles, metal chips, dirt, or other nonvolatile deposits might adversely affect the metallurgical or sanitary condition or stability of a surface, the mechanical operation of a part, component, or system, or contaminate a process fluid. The degree of cleanness required on a surface depends on the application. In some cases, no more than degreasing or removal of gross contamination is necessary. Others, such as food-handling, pharmaceutical, aerospace, and certain nuclear applications, may require extremely high levels of cleanness, including removal of all detectable residual chemical films and contaminants that are invisible to ordinary inspection methods.

[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.14 on Methods of Corrosion Testing.

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*A Summary of Changes section appears at the end of this standard

NOTE 1—The term "iron," when hereinafter referred to as a surface contaminant, shall denote free iron.

1.4 Attainment of surfaces that are free of iron, metallic deposits, and other contamination depends on a combination of proper design, fabrication methods, cleaning and descaling, and protection to prevent recontamination of cleaned surfaces. Meaningful tests to establish the degree of cleanness of a surface are few, and those are often difficult to administer and to evaluate objectively. Visual inspection is suitable for the detection of gross contamination, scale, rust, and particulates, but may not reveal the presence of thin films of oil or residual chemical films. In addition, visual inspection of internal surfaces is often impossible because of the configuration of the item. Methods are described for the detection of free iron and transparent chemical and oily deposits.

1.5 This practice provides definitions and describes good pratices for cleaning, descaling, and passivation of stainless steel parts, but does not provide tests with acceptance criteria to demonstrate that the passivation procedures have been successful. For such tests, it is appropriate to specify one of the practices listed in Specification A967.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (For more specific safety precautions see 7.2.5.3, 7.3.4, Section 8, A1.7, and A2.11.)

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A967 Specification for Chemical Passivation Treatments for Stainless Steel Parts

F21 Test Method for Hydrophobic Surface Films by the Atomizer Test

F22 Test Method for Hydrophobic Surface Films by the Water-Break Test

2.2 *Federal Standard:*[3]

Fed. Std. No. 209e for Clean Room and Work Station Requiring Controlled Environments

3. Design

3.1 Consideration should be given in the design of parts, equipment, and systems that will require cleaning to minimize the presence of crevices, pockets, blind holes, undrainable cavities, and other areas in which dirt, cleaning solutions, or sludge might lodge or become trapped, and to provide for effective circulation and removal of cleaning solutions. In equipment and systems that will be cleaned in place or that cannot be immersed in the cleaning solution, it is advisable to slope lines for drainage: to provide vents at high points and drains at low points of the item or system; to arrange for removal or isolation of parts that might be damaged by the cleaning solution or fumes from the cleaning solutions; to provide means for attaching temporary fill and circulation lines; and to provide for inspection of cleaned surfaces.

3.2 In a complex piping system it may be difficult to determine how effective a cleaning operation has been. One method of designing inspectability into the system is to provide a short flanged length of pipe (that is, a spool piece) at a location where the cleaning is likely to be least effective; the spool piece can then be removed for inspection upon completion of cleaning.

4. Precleaning

4.1 Precleaning is the removal of grease, oil, paint, soil, grit, and other gross contamination preparatory to a fabrication process or final cleaning. Precleaning is not as critical and is generally not as thorough as subsequent cleaning operations. Materials should be precleaned before hot-forming, annealing, or other high-temperature operation, before any descaling operation, and before any finish-cleaning operation where the parts will be immersed or where the cleaning solutions will be reused. Items that are subject to several redraws or a series of hot-forming operations, with intermediate anneals, must be cleaned after each forming operation, prior to annealing. Precleaning may be accomplished by vapor degreasing; immersion in, spraying, or swabbing with alkaline or emulsion cleaners, steam, or high-pressure water-jet (see 6.2).

5. Descaling

5.1 *General*—Descaling is the removal of heavy, tightly adherent oxide films resulting from hot-forming, heat-treatment, welding, and other high-temperature operations. Because mill products are usually supplied in the descaled condition, descaling (except removal of localized scale resulting from welding) is generally not necessary during fabrication of equipment or erection of systems (see 6.3). When necessary, scale may be removed by one of the chemical methods listed below, by mechanical methods (for example, abrasive blasting, sanding, grinding, power brushing), or by a combination of these.

5.2 *Chemical Descaling (Pickling)*—Chemical descaling agents include aqueous solutions of sulfuric, nitric, and hydrofluoric acid as described in Annex A1, Table A1.1, molten alkali or salt baths, and various proprietary formulations.

5.2.1 *Acid Pickling*—Nitric-hydrofluoric acid solution is most widely used by fabricators of stainless steel equipment and removes both metallic contamination, and welding and heat-treating scales. Its use should be carefully controlled and is not recommended for descaling sensitized austenitic stainless steels or hardened martensitic stainless steels or where it can come into contact with carbon steel parts, assemblies, equipment, and systems. See also A1.3. Solutions of nitric acid alone are usually not effective for removing heavy oxide scale.

5.2.2 Surfaces to be descaled are usually precleaned prior to chemical treatment. When size and shape of product permit, total immersion in the pickling solution is preferred. Where immersion is impractical, descaling may be accomplished by

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Standardization Documents Order Desk, Bldg 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

(*1*) wetting the surfaces by swabbing or spraying; or (*2*) by partially filling the item with pickling solution and rotating or rocking to slosh the solution so that all surfaces receive the required chemical treatment. The surface should be kept in contact with agitated solution for about 15 to 30 min or until inspection shows that complete scale removal has been accomplished. Without agitation, additional exposure time may be required. If rocking or rotation are impracticable, pickling solution may be circulated through the item or system until inspection shows that descaling has been accomplished.

5.2.3 Over-pickling must be avoided. Uniform removal of scale with acid pickling depends on the acid used, acid concentration, solution temperature, and contact time (see Annex A1). Continuous exposure to pickling solutions for more than 30 min is not recommended. The item should be drained and rinsed after 30 min and examined to check the effectiveness of the treatment. Additional treatment may be required. Most pickling solutions will loosen weld and heat-treating scale but may not remove them completely. Intermittent scrubbing with a stainless steel brush or fiber-bristle brush, in conjunction with pickling or the initial rinse, may facilitate the removal of scale particles and products of chemical reaction (that is, pickling *smut*).

5.2.4 After chemical descaling, surfaces must be thoroughly rinsed to remove residual chemicals; a neutralization step is sometimes necessary before final rinsing. To minimize staining, surfaces must not be permitted to dry between successive steps of the acid descaling and rinsing procedure, and thorough drying should follow the final water rinse. Chemical descaling methods, factors in their selection, and precautions in their use are described in the *Metals Handbook*.[4] When chemical descaling is necessary, it should be done while the part is in its simplest possible geometry, before subsequent fabrication or installation steps create internal crevices or undrainable spaces that may trap descaling agents, sludge, particles, or contaminated rinse water that might either result in eventual corrosion or adversely affect operation of the item after it is placed in service.

5.3 *Mechanical Descaling*—Mechanical descaling methods include abrasive blasting, power brushing, sanding, grinding, and chipping. Procedural requirements and precautions for some of these methods are given in the *Metals Handbook*.[4] Mechanical descaling methods have the advantage that they do not produce such physical or chemical conditions as intergranular attack, pitting, hydrogen embrittlement, cracks, or smut deposits. For some materials, in particular the austenitic stainless steels when in the sensitized condition and the martensitic stainless steels when in the hardened condition, mechanical descaling may be the only suitable method. Grinding is usually the most effective means of removing localized scale such as that which results from welding. Disadvantages of mechanical descaling are cost, as compared to chemical descaling, and the fact that surface defects (for example, laps, pits, slivers) may be obscured, making them difficult to detect.

5.3.1 Surfaces to be descaled may have to be precleaned. Particular care must be taken to avoid damage by mechanical methods when descaling thin sections, polished surfaces, and close-tolerance parts. After mechanical descaling, surfaces should be cleaned by scrubbing with hot water and fiber brushes, followed by rinsing with clean, hot water.

5.3.2 Grinding wheels and sanding materials should not contain iron, iron oxide, zinc, or other undersirable materials that may cause contamination of the metal surface. Grinding wheels, sanding materials, and wire brushes previously used on other metals should not be used on stainless steel. Wire brushes should be of a stainless steel which is equal in corrosion resistance to the material being worked on.

5.3.3 Clean, previously unused abrasives, such as glass beads or iron-free silica or alumina sand, are recommended for abrasive blasting. Steel shot or grit is generally not recommended because of the possibility of embedding iron particles. The use of stainless steel shot or grit reduces the danger of rusting and iron contamination, but cannot completely eliminate the possibility of embedding residues of iron-oxide scale.

5.3.4 If a totally iron and scale free surface is required, most abrasive blasting may be followed by a brief acid dip (see Annex A2).

6. Cleaning

6.1 *General*—Cleaning includes all operations necessary for the removal of surface contaminants from metals to ensure (*1*) maximum corrosion resistance of the metal; (*2*) prevention of product contamination; and (*3*) achievement of desired appearance. Cleanness is a perishable condition. Careful planning is necessary to achieve and maintain clean surfaces, especially where a high degree of cleanness is required. Selection of cleaning processes is influenced mainly by the type of contaminant to be removed, the required degree of cleanness, and cost. If careful control of fabrication processes, sequencing of cleaning and fabrication operations, and measures to prevent recontamination of cleaned surfaces are exercised, very little special cleaning of the finished item or system may be necessary to attain the desired level of cleanness. If there is a question concerning the effectiveness of cleaning agents or procedures, or the possible adverse effects of some cleaning agents or procedures on the materials to be cleaned, trial runs, using test specimens and sensitive inspection techniques may be desirable. Descriptions, processes, and precautions to be observed in cleaning are given in the *Metals Handbook*.[4] Proprietary cleaners may contain harmful ingredients, such as chlorides or sulfur compounds, which could adversely affect the performance of a part, equipment, or system under service conditions. It is recommended that the manufacturer of the cleaner be consulted if there is reason for concern.

NOTE 2—Instances are known where stainless steel vessels have stress cracked before start-up due to steaming out or boiling out with a chloride-containing detergent.

6.2 *Cleaning Methods*—Degreasing and general cleaning may be accomplished by immersion in, swabbing with, or spraying with alkaline, emulsion, solvent, or detergent cleaners or a combination of these; by vapor degreasing; by ultrasonics using various cleaners; by steam, with or without a cleaner; or

[4] "Surface Cleaning, Finishing, and Coating," *Metals Handbook,* Am. Soc. Metals, 9th ed., Vol 5, 1982.

by high-pressure water-jetting. The cleaning method available at any given time during the fabrication or installation of a component or system is a function of the geometric complexity of the item, the type of contamination present, the degree of cleanliness required, and cost. Methods commonly used for removing deposited contaminants (as opposed to scale) are described briefly below and in greater detail (including factors to be considered in their selection and use) in the *Metals Handbook*[4] and the *SSPC Steel Structures Painting Handbook.*[5] The safety precautions of 8.6 must be observed in the use of these methods. Particular care must be exercised when cleaning closed systems and items with crevices or internal voids to prevent retention of cleaning solutions and residues.

6.2.1 *Alkaline Cleaning* is used for the removal of oily, semisolid, and solid contaminants from metals. To a great extent the solutions used depend on their detergent qualities for cleaning action and effectiveness. Agitation and temperature of the solution are important.

6.2.2 *Emulsion Cleaning* is a process for removing oily deposits and other common contaminants from metals by the use of common organic solvents dispersed in an aqueous solution with the aid of a soap or other emulsifying agent (an emulsifying agent is one which increases the stability of a dispersion of one liquid in another). It is effective for removing a wide variety of contaminants including pigmented and unpigmented drawing compounds and lubricants, cutting fluids, and residues resulting from liquid penetrant inspection. Emulsion cleaning is used when rapid, superficial cleaning is required and when a light residual film of oil is not objectionable.

6.2.3 *Solvent Cleaning* is a process for removing contaminants from metal surfaces by immersion or by spraying or swabbing with common organic solvents such as the aliphatic petroleums, chlorinated hydrocarbons, or blends of these two classes of solvents. Cleaning is usually performed at or slightly above room temperature. Except for parts with extremely heavy contamination or with hard-to-reach areas, or both, good agitation will usually eliminate the need for prolonged soaking. Virtually all metal can be cleaned with the commonly used solvents unless the solvent has become contaminated with acid, alkali, oil, or other foreign material. Chlorinated solvents are not recommended for degreasing of closed systems or items with crevices or internal voids.

6.2.4 *Vapor Degreasing* is a generic term applied to a cleaning process that employs hot vapors of a volatile chlorinated solvent to remove contaminants, and is particularly effective against oils, waxes, and greases. The cleanness and chemical stability of the degreasing solvent are critical factors in the efficiency of the vapor and possible chemical attack of the metal. Water in the degreasing tank or on the item being cleaned may react with the solvent to form hydrochloric acid, which may be harmful to the metal. No water should be present in the degreasing tank or on the item being cleaned. Acids, oxidizing agents, and cyanides must be prevented from contaminating the solvent. Materials such as silicones cause foaming at the liquid-vapor interface and may result in recontamination of the workpiece as it is removed from the degreaser. Vapor degreasing with chlorinated solvents is not recommended for closed systems or items with internal voids or crevices.

6.2.5 *Ultrasonic Cleaning* is often used in conjunction with certain solvent and detergent cleaners to loosen and remove contaminants from deep recesses and other difficult to reach areas, particularly in small work-pieces. Cavitation in the liquid produced by the high frequency sound causes micro agitation of the solvent in even tiny recesses of the workpiece, making the method especially desirable for cleaning parts or assemblies having an intricate configuration. For extremely high levels of surface cleanness, high-purity solvents (1 ppm total nonvolatile residue) are required.

6.2.6 *Synthetic Detergents* are extensively used as surface-active agents because they are freer rinsing than soaps, aid in soils dispersion, and prevent recontamination. They are effective for softening hard water and in lowering the surface and interfacial tensions of the solutions. Synthetic detergents, in particular, should be checked for the presence of harmful ingredients as noted in 6.1.

6.2.7 *Chelate Cleaning*—Chelates are chemicals that form soluble, complex molecules with certain metal ions, inactivating the ions in solution so they cannot normally react with another element or ions to produce precipitates or scale. They enhance the solubility of scales and certain other contaminants, do not precipitate different scales when the cleaning solution becomes spent, and can be used on some scales and contaminants that even mineral acids will not attack. When properly used (chelating agents must be continuously circulated and must be maintained within carefully controlled temperature limits), intergranular attack, pitting, and other harmful effects are minimal. Chelating agents are particularly useful for cleaning installed equipment and systems.

6.2.8 *Mechanical Cleaning* (also see 5.3)—Abrasive blasting, vapor blasting using a fine abrasive suspended in water, grinding, or wire brushing are often desirable for removing surface contaminants and rust. Cleanliness of abrasives and cleaning equipment is extremely important to prevent recontamination of the surfaces being cleaned. Although surfaces may appear visually clean following such procedures, residual films which could prevent the formation of an optimum passive condition may still be present. Subsequent treatment such as additional iron-free abrasive cleaning methods, acid cleaning, passivation, or combinations of these is, therefore, required for stainless steel parts, equipment, and systems to be used where corrosion resistance is a prime factor to satisfy performance and service requirements, or where product contamination must be avoided.

6.2.9 *Steam Cleaning* is used mostly for cleaning bulky objects that are too large for soak tanks or spray-washing equipment. It may be used with cleaning agents such as emulsions, solvents, alkalis, and detergents. Steam lances are frequently used for cleaning piping assemblies. Steam pressures from 50 to 75 psi (345 to 515 kPa) are usually adequate (see 6.1).

[5] *Good Painting Practices,*Steel Structures Painting Council, Vol 1, 1982, Chapters 2.0–2.9, 3.1–3.2.

6.2.10 *Water-Jetting* at water pressures of up to 10 000 psi (70 mPa) is effective for removing grease, oils, chemical deposits (except adsorbed chemicals), dirt, loose and moderately adherent scale, and other contaminants that are not actually bonded to the metal. The method is particularly applicable for cleaning piping assemblies which can withstand the high pressures involved; self-propelled nozzles or "moles" are generally used for this purpose.

6.2.11 *Acid Cleaning* is a process in which a solution of a mineral or organic acid in water, sometimes in combination with a wetting agent or detergent or both, is employed to remove iron and other metallic contamination, light oxide films, shop soil, and similar contaminants. Suggested solutions, contact times, and solution temperatures for various alloys are given in Annex A2. Acid cleaning is not generally effective for removal of oils, greases, and waxes. Surfaces should be precleaned to remove oils and greases before acid cleaning. Common techniques for acid cleaning are immersion, swabbing, and spraying. Maximum surface quality is best achieved by using a minimum cleaning time at a given acid concentration and temperature. After acid cleaning the surfaces must be thoroughly rinsed with clean water to remove all traces of the acid and thoroughly dried after the final water rinse. To minimize staining, surfaces must not be permitted to dry between successive steps of the acid cleaning and rinsing procedure. A neutralizing treatment may be required under some conditions; if used, neutralization must be followed by repeated water rinsing to remove all trace of the neutralizing agent followed by thorough drying after the final water rinse. Acid cleaning is not recommended where mechanical cleaning or other chemical methods will suffice on the basis of intended use and, as may be necessary, on inspection tests (see 7.2 and 7.3). Requirements for superfluous cleaning and inspection testing can result in excessive costs. Acid cleaning, if not carefully controlled, may damage the surface and may result in further contamination of the surface.

6.3 *Cleaning of Welds and Weld-Joint Areas*—The joint area and surrounding metal for several inches back from the joint preparation, on both faces of the weld, should be cleaned immediately before starting to weld. Cleaning may be accomplished by brushing with a clean stainless steel brush or scrubbing with a clean, lint-free cloth moistened with solvent, or both. When the joint has cooled after welding, remove all accessible weld spatter, welding flux, scale, arc strikes, etc., by grinding. According to the application, some scale or heat temper may be permissible on the nonprocess side of a weld, but should be removed from the process side if possible. If chemical cleaning of the process side of the weld is deemed necessary, the precautions of this standard must be observed. Austenitic stainless steels in the sensitized condition should generally not be descaled with nitric-hydrofluoric acid solutions. Welds may also be cleaned as described in Table A2.1, Part III, Treatment *P* and *Q* (also see 5.2.3 and 5.2.4).

6.4 *Final Cleaning or Passivation, or Both*—If proper care has been taken in earlier fabrication and cleaning, final cleaning may consist of little more than scrubbing with hot water or hot water and detergent (such as trisodium phosphate, TSP), using fiber brushes. Detergent washing must be followed by a hot-water rinse to remove residual chemicals. Spot cleaning to remove localized contamination may be accomplished by wiping with a clean, solvent-moistened cloth. If the purchaser specifies passivation, the final cleaning shall be in accordance with the requirements of Table A2.1, Part II. When the stainless steel parts are to be used for applications where corrosion resistance is a prime factor to achieve satisfactory performance and service requirements, or where product contamination must be avoided, passivation followed by thorough rinsing several times with hot water and drying thoroughly after the final water rinse is recommended, whenever practical.

6.5 *Precision Cleaning*—Certain nuclear, space, and other especially critical applications may require that only very high-purity alcohols, acetone, ketones, or other *precision cleaning agents* be used for final cleaning or recleaning of critical surfaces after fabrication advances to the point that internal crevices, undrainable spaces, blind holes, or surfaces that are not accessible for thorough scrubbing, rinsing, and inspection are formed. Such items are often assembled under clean-room conditions (see 8.5.5) and require approval, by the purchaser, of carefully prepared cleaning procedures before the start of fabrication.

6.6 *Cleaning of Installed Systems*—There are two approaches to cleaning installed systems. In the first, which is probably adequate for most applications, cleaning solutions are circulated through the completed system after erection, taking care to remove or protect items that could be damaged during the cleaning operation. In the second approach, which may be required for gaseous or liquid oxygen, liquid metal, or other reactive-process solutions, piping and components are installed in a manner to avoid or minimize contamination of process-solution surfaces during erection so that little additional cleaning is necessary after erection; post-erection flushing, if necessary, is done with the process fluid. If process surfaces are coated with an appreciable amount of iron oxide, a chelating treatment or high-pressure water-jetting treatment should be considered in place of acid treatment (see 6.2.7 and 6.2.10).

6.6.1 *Post-Erection Cleaning*—Circulate hot water to which a detergent has been added, for at least 4 to 8 h. A water temperature of at least 140 to 160°F (60 to 71°C) is recommended (see 6.1). Rinse by circulating clean hot water until the effluent is clear. If excessive particulate matter is present, the cleaning cycle may be preceded with a high-pressure steam blow, repeating as necessary until a polished-aluminum target on the outlet of the system is no longer dulled and scratched by particulates loosened by the high-velocity steam. Valves and similar items must be protected from damage during a steam blow.

6.6.2 If metallic iron is indicated by one of the methods suggested in Section 7, it can be removed by circulating one of the acid cleaning solutions suggested in Annex A2 at room temperature until laboratory determination for iron, made on samples of the solution taken hourly, indicates no further increase in iron content, after which circulation may be stopped and the system drained. After this treatment, circulate clean hot water (that is, without detergent) through the system for 4 h to remove all traces of acid and corrosion product resulting from the acid treatment, or until the pH of the rinse water returns to neutral.

6.6.3 In critical systems where post-erection cleaning is not desirable (for example, liquid oxygen or nuclear reactor primary coolant systems), on-site erection may be conducted under clean-room conditions. Erection instructions may require that wrapping and seals of incoming materials and equipment be kept intact until the item is inside the clean area, and that careful surveillance be exercised to prevent foreign materials (for example, cleaning swabs or tools) from being dropped or left in the system. Where contamination does occur, the cleaning procedure usually is developed through consultation between the erector and the purchaser (or his site representative). Frequently, post-erection flushing is accomplished by circulating the process fluid through the system until contamination is reduced to tolerable levels.

6.6.4 When cleaning critical installed systems, do not permit the process surfaces to dry between successive cleaning and rinsing steps, or between the final rinse and filling with the layup solution.

7. Inspection After Cleaning

7.1 *General*—Inspection techniques should represent careful, considered review of end use requirements of parts, equipment, and systems. There is no substitute for good, uniform, cleaning practices which yield a metallurgically sound and smooth surface, followed by adequate protection to preserve that condition. Establishment of the most reliable tests and test standards for cleanness are helpful in attaining the desired performance of parts, equipment, and systems. Testing should be sufficiently extensive to ensure the cleanness of all surfaces exposed to process fluids when in service. The following represent some tests that have been successfully applied to stainless steels. The purchaser shall have the option of specifying in his purchase documents that any of these quality assurance tests be used as the basis for acceptability of the cleanness or state of passivity of the stainless steel item.

7.2 *Gross Inspection:*

7.2.1 *Visual*—Items cleaned in accordance with this practice should be free of paint, oil, grease, welding flux, slag, heat-treating and hot-forming scale (tightly adherent scale resulting from welding may be permissible on some surfaces), dirt, trash, metal and abrasive particles and chips, and other gross contamination. Some deposited atmospheric dust will normally be present on exterior surfaces but should not be present on interior surfaces. Visual inspection should be carried out under a lighting level, including both general and supplementary lighting, of at least 100 footcandles (1076 lx), and preferably 250 footcandles (2690 lx) on the surfaces being inspected. Visual inspection should be supplemented with borescopes, mirrors, and other aids, as necessary, to properly examine inaccessible or difficult-to-see surfaces. Lights should be positioned to prevent glare on the surfaces being inspected.

7.2.2 *Wipe Tests*—Rubbing of a surface with a clean, lint-free, white cotton cloth, commercial paper product, or filter paper moistened (but not saturated) with high-purity solvent (see 6.5), may be used for evaluating the cleanness of surfaces not accessible for direct visual inspection. Wipe tests of small diameter tubing are made by blowing a clean white felt plug, slightly larger in diameter than the inside diameter of the tube, through the tube with clean, dry, filtered compressed air. Cleanness in wipe tests is evaluated by the type of contamination rubbed off on the swab or plug. The presence of a smudge on the cloth is evidence of contamination. In cases of dispute concerning the harmful nature of the contamination, a sample of the smudge may be transferred to a clean quartz microscope slide for infrared analysis. The wipe test is sometimes supplemented by repeating the test with a black cloth to disclose contaminants that would be invisible on a white cloth.

7.2.3 *Residual Pattern*—Dry the cleaned surface after finish-cleaning at 120°F (49°C) for 20 min. The presence of stains or water spots on the dried surfaces indicates the presence of residual soil and incomplete cleaning. The test is rapid but not very sensitive.

7.2.4 *Water-Break Test*—This is a test for the presence of hydrophobic contaminants on a cleaned surface. It is applicable only for items that can be dipped in water and should be made with high-purity water. The test procedure and interpretation of results are described in Test Method F22. The test is moderately sensitive.

7.2.5 *Tests for Free Iron: Gross Indications*—When iron contamination is clearly visible, items should be cleaned in accordance with this practice.

7.2.5.1 *Water-Wetting and Drying*—Formation of rust stains may be accelerated by periodically wetting the surface with preferably distilled or deionized water or clean, fresh, potable tap water. The wet-dry cycles should be such that the sample remains dry for a total of 8 h in a 24-h test period. After completion of this test, the surface should show no evidence of rust stains or other corrosion products.

7.2.5.2 *High-Humidity Test*—Subject the surface to a 95 to 100 % humidity at 100 to 115°F (38 to 46°C) in a suitable humidity cabinet for 24 to 26 h. After completion of this test, the surface should show no evidence of rust stains or other corrosion products.

7.2.5.3 *Copper Sulfate Test*—This method is recommended for the detection of metallic iron or iron oxide on the surface of austenitic 200 and 300 Series, the precipitation hardening alloys, and the ferritic 400 Series stainless steels containing 16% chromium or more. It is not recommended for the martensitic and lower chromium ferritic stainless steels of the 400 Series since the test will show a positive reaction on these materials. This test is hypersensitive and should be used and interpreted only by personnel familiar with its limitations. (**Warning—** This test must not be applied to surfaces of items to be used in food processing.) The test solution is prepared by first adding sulfuric acid to distilled water and then dissolving copper sulfate in the following proportions (**Warning—** Always add acid to cold water.):

	250-cm^3 Batch
Distilled water	
Sulfuric acid (H_2SO_4, sp gr 1.84)	1 cm^3
Copper sulfate ($CuSO_4 \cdot 5H_2O$)	4 g

Swab the surface to be inspected with test solution, applying additional solution if needed to keep the surface wet for a period of 6 min. The specimen shall be rinsed and dried in a manner not to remove any deposited copper. Copper deposit will indicate the presence of free iron.

NOTE 3—The copper sulfate test as set forth above is not applicable to surgical and dental instruments made of hardened martensitic stainless steels. Instead, a specialized copper sulfate test is extensively used for the purpose of detecting free iron and determining overall good manufacturing practice. Copper deposits at the surface of such instruments are wiped with moderate vigor to determine if the copper is adherent or nonadherent. Instruments with nonadherent copper are considered acceptable. The specialized test solution is prepared by first adding 5.4 cm^3 of sulfuric acid (H_2SO_4, sp gr 1.84) to 90 cm^3 of distilled water and then dissolving 4 g of copper sulfate ($CuSO_4 \cdot 5H_2O$).

7.3 *Precision Inspection:*

7.3.1 *Solvent-Ring Test* is a test to reveal the presence of tightly adherent transparent films that may not be revealed by visual inspection or wipe tests. A comparison standard is prepared by placing on a clean quartz microscope slide a single drop of high-purity solvent and allowing it to evaporate. Next place another drop on the surface to be evaluated, stir briefly, and transfer, using a clean capillary or glass rod, to a clean quartz microscope slide and allow the drop to evaporate. Make as many test slides as necessary to give a reasonable sample of the surface being examined. If foreign material has been dissolved by the solvent, a distinct ring will be formed on the outer edge of the drop as it evaporates. The nature of the contaminant can be determined by infrared analysis, comparing the infrared analysis with that of the standard.

7.3.2 *Black Light Inspection* is a test suitable for the detection of certain oil films and other transparent films that are not detectable under white light. In an area that is blacked out to white light, inspect all visible accessible surfaces with the aid of a new, flood-type, ultraviolet lamp. For inaccessible areas, use a wipe test as described in 7.2.2 and subject the used cloth or plug to ultraviolet lamp inspection in a blacked-out area. Fluorescence of the surface, cloth, or plug indicates the presence of contaminants. The nature of the contamination can be determined by subjecting a sample of the contaminant, that has been transferred to a clean quartz microscope slide, to infrared analysis. The test will not detect straight-chain hydrocarbons such as mineral oils.

7.3.3 *Atomizer Test* is a test for the presence of hydrophobic films. It is applicable to both small and large surfaces that are accessible for direct visual examination, and is about 100× more sensitive than the water-break test. The test procedure and interpretation of results are described in Test Method F21. High-purity water should be used for the test.

7.3.4 *Ferroxyl Test for Free Iron* is a highly sensitive test and should be used only when even traces of free iron or iron oxide might be objectionable. It should be made only by personnel familiar with its limitations. The test can be used on stainless steel to detect iron contamination, including iron-tool marks, residual-iron salts from pickling solutions, iron dust, iron deposits in welds, embedded iron or iron oxide, etc. The test solution is prepared by first adding nitric acid to distilled water and then adding potassium ferricyanide, in the following proportions:

Distilled water	94 weight %	1000 cm^3	1 gal
Nitric acid (60–67 %)	3 weight %	20 cm^3	⅛ pt
Potassium ferricyanide	3 weight %	30 g	4 oz

Apply solution with an aluminum, plastic, glass, or rubber atomizer having no iron or steel parts, or a swab (atomizer spray is preferred).

7.3.4.1 The appearance of a blue stain (within 15 s of application) is evidence of surface iron contamination (several minutes may be required for detection of oxide scale). The solution should be removed from the surface as quickly as possible after testing using water or, if necessary, white vinegar or a solution of 5 to 20 weight % acetic acid and scrubbing with a fiber brush. Flush the surface with water several times after use of vinegar or acetic acid.[6]

NOTE 4—Potassium ferricyanide is not a dangerous poison as are the simple cyanides. However, when heated to decomposition or in contact with concentrated acid, it emits highly toxic cyanide fumes.

NOTE 5—Rubber gloves, clothing, and face shields should be worn when applying the test solution, and inhalation of the atomized spray should be avoided.

NOTE 6—The test is not recommended for process-surfaces of equipment that will be used for processing food, beverages, pharmaceuticals, or other products for human consumption unless all traces of the test solution can be thoroughly removed.

NOTE 7—The test solution will change color on standing and must be mixed fresh prior to each use.

8. Precautions

8.1 *Minimizing Iron Contamination*—Iron contamination on stainless steel parts, components, and systems is almost always confined to the surface. If reasonable care is taken in fabrication, simple inexpensive cleaning procedures may suffice for its removal, and very little special cleaning should be required. Fabrication should be confined to an area where only the one grade of material is being worked. Powder cutting should be minimized or prohibited. Handling equipment such as slings, hooks, and lift-truck forks should be protected with clean wood, cloth, or plastic buffers to reduce contact with the iron surfaces. Walking on corrosion-resistant alloy surfaces should be avoided; where unavoidable, personnel should wear clean shoe covers each time they enter. Kraft paper, blotting paper, paperboard, flannel, vinyl-backed adhesive tape or paper, or other protective material should be laid over areas where personnel are required to walk. Shearing tables, press breaks, layout stands, and other carbon-steel work surfaces should be covered with clean kraft paper, cardboard, or blotting paper to reduce the amount of contact with the carbon steel. Hand tools, brushes, molding tools, and other tools and supplies required for fabrication should be segregated from similar items used in the fabrication of carbon steel equipment, and should be restricted to use on the one material; tools and supplies used with other materials should not be brought into the fabrication area. Tools and fixtures should be made of hardened tool steel or chrome-plated steel. Wire brushes should be stainless steel, or of an alloy composition similar to the steel being cleaned, and should not have been previously used on other materials. Only new, washed sand, free of iron particles, and stainless steel chills and chaplets should be used for casting.

[6] For further information see *Journal of Materials,* ASTM, Vol 3, No. 4, December 1968, pp. 983-995.

8.2 *Reuse of Cleaning and Pickling Solutions*—Cleaning and pickling agents are weakened and contaminated by materials and soil being removed from surfaces as they are cleaned. Solutions may become spent or depleted in concentration after extended use, and it is necessary to check concentrations and to replace or replenish solutions when cleaning or pickling action slows. It may be impractical or uneconomical to discard solutions after a single use, even in precision cleaning operations (that is, finish-cleaning using very high-purity solvents and carried out under clean-room and rigidly controlled environmental conditions). When solutions are re-used, care must be taken to prevent the accumulation of sludge in the bottom of cleaning tanks; the formation of oil, scums, and undissolved matter on liquid surfaces; and high concentrations of emulsified oil, metal or chemical ions, and suspended solids in the liquids. Periodic cleaning of vats and degreasing tanks, decanting, periodic bottom-drain, agitation of solutions, and similar provisions are essential to maintain the effectiveness of solutions. Care must be taken to prevent water contamination of trichloroethylene and other halogenated solvents, both while in storage and in use. Redistillation and filtering of solvents and vapor-degreasing agents are necessary before reuse. Makeup is often required to maintain concentrations and pH of cleaning solutions at effective levels. Do not overuse chemical cleaners, particularly acids and vapor-degreasing solvents; if light films or oily residues remain on the metal surfaces after use of such agents, additional scrubbing with hot water and detergent, followed by repeated rinsing with large quantities of hot water, may be necessary.

8.3 *Rinse Water*—Ordinary industrial or potable waters are usually suitable for most metal-cleaning applications. Biologically tested potable water should be used for final rinsing of food-handling, pharmaceutical, dairy, potable-water, and other sanitary equipment and systems. Rinsing and flushing of critical components and systems after finish-cleaning often requires high-purity deionized water, having strict controls on halide content, pH, resistivity, turbidity, and nonvolatile residues. Analytical methods that may be used for establishing the purity of rinse water should be demonstrated to have the sensitivity necessary to detect specified impurity levels; the analytical methods given in the *Annual Book of ASTM Standards,* Vol 03.05, are recommended for referee purposes in case of dispute. To minimize the use of costly high-purity water, preliminary rinses can often be made with somewhat lesser quality water, followed by final rinsing with the high-purity water. It is also possible in many cases to use effluent or overflow from the final rinse operation for preliminary rinsing of other items.

8.4 *Circulation of Cleaning Solutions and Rinse Water*—For restricted internal surfaces (for example, small diameter piping systems or the shell or tube side of a heat exchanger), high-velocity, turbulent flow of cleaning solutions and rinse water may be necessary to provide the scrubbing action needed for effective cleaning and rinsing. The velocity required is a function of the degree of cleanness required and the size of particles that are permissible in the system after the start of operation. For example, if particles between 500 and 1000 µm are acceptable to remain, a mean flushing velocity of 1 to 2 ft/s (0.3 to 0.6 m/s) may be sufficient for pipe diameters of 2 in. and smaller; to remove 100 to 200-µm particles, a mean flushing velocity of 3 to 4 ft/s (0.9 to 1.2 m/s) may be required.

8.5 *Protection of Cleaned Surfaces*—Measures to protect cleaned surfaces should be taken as soon as final cleaning is completed, and should be maintained during all subsequent fabrication, shipping, inspection, storage, and installation.

8.5.1 Do not remove wrappings and seals from incoming materials and components until they are at the use site, ready to be used or installed. If wrappings and seals must be disturbed for receiving inspection, do not damage them, remove no more than necessary to carry out the inspection, and rewrap and reseal as soon as the inspection is complete. For critical items that were cleaned by the supplier, and that will not be given further cleaning at the use site or after installation, the condition of seals and wrappings should be inspected regularly and at fairly short intervals while the item is in storage.

8.5.2 Finish-cleaned materials and components should not be stored directly on the ground or floor, and should not be permitted, insofar as practicable, to come in contact with asphalt, galvanized or carbon steel, mercury, zinc, lead, brass, low-melting point metals, or alloys or compounds of such materials. Acid cleaning of surfaces that have been in contact with such materials may be necessary to prevent failure of the item when subsequently heated. The use of carbon or galvanized steel wire for bundling and galvanized steel identification tags should be avoided.

8.5.3 Store materials and equipment, when in process, on wood skids or pallets or on metal surfaces that have been protected to prevent direct contact with stainless steel surfaces. Keep openings of hollow items (pipe, tubing, valves, tanks, pumps, pressure vessels, and so forth) capped or sealed at all times except when they must be open to do work on the item, using polyethylene, nylon, TFE-fluorocarbon plastic, or stainless steel caps, plugs, or seals. Where cleanness of exterior surfaces is important, keep the item wrapped with clear polyethylene or TFE-fluorocarbon plastic sheet at all times except when it is actually being worked on. Avoid asphalt-containing materials. Canvas, adhesive paper or plastics such as poly(vinyl chloride) may decompose in time to form corrosive substances, for example, when exposed to sunlight or ultraviolet light. The reuse of caps, plugs, or packaging materials should be avoided unless they have been cleaned prior to reuse.

8.5.4 Clean stainless steel wire brushes and hand tools before reuse on corrosion-resistant materials; if they have not been cleaned and if they could have been used on electrolytically different materials, the surfaces contacted by the tools should be acid-cleaned. The use of soft-face hammers or terne (lead)-coated, galvanized, or unprotected carbon steel tables, jigs, racks, slings, or fixtures should be avoided (see 8.5.2).

8.5.5 If close control of particulate contamination is required, particularly of internal surfaces, the latter stages of assembly and fabrication may have to be carried out in a clean room. For most large items an air cleanliness class (see Fed. Std. 209e) at the work surface of Class 50 000 to 100 000 (that is, a maximum of from 50 000 to 100 000 particles 0.5 µm or larger suspended in the air) is probably sufficient.

NOTE 8—Clean room is a specially constructed enclosure in which intake air is filtered so that the air at a work station contains no more than a specified number of particles of a specified size; special personnel and housekeeping procedures are required to maintain cleanness levels in a clean room (see Fed. Std. 209e).

8.5.6 Workmen handling finished cleaned surfaces of critical items should wear clean lint-free cotton, nylon or dacron cloth or polyethylene film gloves. Rubber or plastic gloves are suitable during precleaning operations or cleaning of non-critical surfaces.

8.5.7 Installed piping systems are often *laid up wet;* that is, they are filled with water (or process fluid) after in-place cleaning until ready to be placed in service. Storage water should be of the same quality as the makeup water for the system, and should be introduced in a manner that it directly replaces the final flush water without permitting the internal surfaces of the system to dry.

8.5.8 Equipment and assemblies for critical applications may be stored and shipped with pressurized, dry, filtered, oil-free nitrogen to prevent corrosion until they are ready to be installed. Means must be provided for maintaining and monitoring the gas pressure during shipping and storage. If the item is to be shipped to or through mountains or other areas where the altitude varies greatly from that where it was pressurized, consideration must be given to the effect of that change in altitude on the pressure inside the item, and possible rupture or loss of seals.

8.5.9 Pressure-sensitive tape is often used for sealing or protective covers, seals, caps, plugs, and wrappings. If possible, the gummed surface of the tape should not come in contact with stainless steel surfaces. If tape has come in contact with the metal, clean it with solvent or hot water, and vigorous scrubbing.

8.5.10 Protective adhesive papers or plastics are often used to protect the finish of sheet stock and parts. These materials may harden or deteriorate when subjected to pressure or sunlight, and damage the surface. These materials may also decompose in time to form substances as described in 8.5.3. Protective material should be removed when its function is complete or its condition monitored for decomposition or deterioration until it is removed.

8.6 *Safety*—Cleaning operations often present numerous hazards to both personnel and facilities. Manufactures' Safety Data Sheets (MSDS) should be consulted to determine the hazards of handling specific chemicals.

8.6.1 Precautions must be taken to protect personnel, equipment, and facilities. This includes provisions for venting of explosive or toxic reaction-product gases, safe disposal of used solutions, provision of barriers and warning signs, provisions for safe transfer of dangerous chemicals, and maintenance of constant vigilance for hazards and leaks during the cleaning operation.

8.6.2 The physical capability of the item or system to be cleaned, together with its foundations, to withstand the loads produced by the additional weight of fluids used in the cleaning operation, must be established before the start of cleaning operations.

8.6.3 Insofar as possible, chemicals having explosive, toxic, or obnoxious fumes should be handled out of doors.

8.6.4 The area in which the cleaning operation is being conducted should be kept clean and free of debris at all times, and should be cleaned upon completion of the operation.

8.7 *Disposal of Used Solutions and Water*—Federal, state, and local safety and water pollution control regulations should be consulted, particularly when large volumes of chemical solutions must be disposed of. Controlled release of large volumes of rinse water may be necessary to avoid damaging sewers or stream beds.

9. Keywords

9.1 austenitic stainless steels; cleaning; corrosion; corrosive service applications; descaling; ferritic stainless steels; martensitic stainless steels; pickling; stainless steels

ANNEXES

(Mandatory Information)

A1. RECOMMENDATIONS AND PRECAUTIONS FOR ACID DESCALING (PICKLING) OF STAINLESS STEEL

(See Table A1.1.)

A1.1 Where size and shape permit, immersion in the acid solution is preferred; when immersion is not practicable, one of the following room-temperature methods may be used:

A1.1.1 For interior surfaces, partially fill item with solution and rock, rotate, or circulate so that all inside surfaces are thoroughly wetted. Keep surfaces in contact with acid solution until inspection shows that scale is completely removed. Additional exposure without agitation may be needed. Treat exterior surfaces in accordance with A1.1.2.

A1.1.2 Surfaces that cannot be pickled by filling the item may be descaled by swabbing or spraying with acid solution for about 30 min, or until inspection shows that scale is completely removed.

TABLE A1.1 Acid Descaling (Pickling) of Stainless Steel

Alloy[A]	Condition[B]	Treatment			
		Code	Solution, Volume, %[C]	Temperature °F (°C)	Time, Minutes
200, 300, and 400 Series, precipitation hardening, and maraging alloys (except free-machining alloys)	fully annealed only	A	H_2SO_4, 8–11 %[D] Follow by treatment D or F, Annex A2, as appropriate	150–180 (66–82)	5–45 max[E]
200 and 300 Series; 400 Series containing Cr 16 % or more; precipitation-hardening alloys (except free-machining alloys)	fully annealed only	B	HNO_3, 15–25 % plus HF, 1–8 %[F,G]	70–140 max (21–60)	5–30[E]
All free-machining alloys and 400 Series containing less than Cr 16 %	fully annealed only	C	HNO_3, 10–15 % plus HF, ½–1½ %[F,G]	70 (up to 140 with caution)	5–30[E]

[A] This table is also applicable to the cast grades equivalent to the families of wrought materials listed.
[B] Other heat treatments may be acceptable if proven by experience: see 5.2.1, A2.4, and A2.5 for further information.
[C] Solution prepared from reagents of following weight %: H_2SO_4, 98; HNO_3, 67; HF, 70.
[D] Tight scale may be removed by a dip in this solution for a few minutes followed by water rinse and nitric-hydrofluoric acid treatment as noted.
[E] Minimum contact times necessary to obtain the desired surface should be used in order to prevent over-pickling. Tests should be made to establish correct procedures for specific applications.
[F] For reasons of convenience and handling safety, commercial formulations containing fluoride salts may be found useful in place of HF for preparing nitric-hydrofluoric acid solutions.
[G] After pickling and water rinsing, an aqueous caustic permanganate solution containing NaOH, 10 weight % and $KMnO_4$, 4 weight %, 160 to 180°F (71 to 82°C), 5 to 60 min, may be used as a final dip for removal of smut, followed by thorough water rinsing and drying.

A1.2 Severe pitting may result from prolonged exposure to certain acid solutions if the solution becomes depleted or if the concentration of metallic salts becomes too high as a result of prolonged use of the solution; the concentration of iron should not exceed 5 weight %; take care to prevent over-pickling.

A1.3 Nitric-hydrofluoric acid solutions may intergranularly corrode certain alloys if they have been sensitized by improper heat treatment or by welding. Crevices resulting from intergranular attack can collect and concentrate halogens under service conditions or during cleaning or processing with certain chemicals; these halogens can cause stress-corrosion cracking. These alloys should generally not be acid-pickled while in the sensitized condition. Consideration should be given to stabilized or low-carbon grades if acid pickling after welding is unavoidable.

A1.4 Some latitude is permissible in adjusting acid concentrations, temperatures, and contact times. In general, lower values in this table apply to lower alloys, and higher values to higher alloys. Close control over these variables is necessary once proper values are established in order to preserve desired finishes or close dimensional tolerances, or both.

A1.5 Materials must be degreased before acid pickling and must be vigorously brushed with hot water and a bristle brush or with high-pressure water jet on completion of pickling; pH of final rinse water should be between 6 and 8 for most applications, or 6.5 to 7.5 for critical applications. To minimize staining, surfaces must not be permitted to dry between successive steps of the acid descaling and rinsing procedure. Thorough drying should follow the final water rinse.

A1.6 Hardenable 400 Series alloys, maraging alloys, and precipitation-hardening alloys in the hardened condition are subject to hydrogen embrittlement or intergranular attack by acids. Descaling by mechanical methods is recommended where possible. If acid pickling is unavoidable, parts should be heated at 250 to 300°F (121 to 149°C) for 24 h immediately following acid treatment to drive off the hydrogen and reduce the susceptibility to embrittlement.

A1.7 Proper personnel protection, including face shields, rubber gloves, and rubber protective clothing, must be provided when handling acids and other corrosive chemicals. Adequate ventilation and strict personnel-access controls must be maintained in areas where such chemicals are being used.

A2. RECOMMENDATIONS AND PRECAUTIONS FOR ACID CLEANING OF STAINLESS STEEL (See Table A2.1.)

A2.1 Treatments shown are generally adequate for removal of contamination without seriously changing surface appearance of parts. Passivated parts should exhibit a clean surface and should show no etching, pitting, or frosting. The purchaser shall specify whether a slight discoloration is acceptable. Passivated parts should not exhibit staining attributable to the presence of free iron particles imbedded in the surface when subjected to the test described in 7.2.5.1. For specific requirements for items to be used in corrosive service or where surface appearance is critical, trials should be conducted to establish satisfactory procedures.

A2.2 The high-carbon and free-machining alloys may be subject to etching or discoloration in nitric acid. This tendency can be minimized by the use of high acid concentrations with inhibitors such as $Na_2Cr_2O_7 \cdot 2H_2O$ and $CuSO_4 \cdot 5H_2O$. Oxidizing action increases with increasing concentration of nitric acid; additional oxidizing action is provided by $Na_2Cr_2O_7 \cdot 2H_2O$. Avoid acid cleaning when possible; use mechanical cleaning followed by scrubbing with hot water and detergent, final thorough water rinsing and drying.

A2.3 Inhibitors may not always be required to maintain bright finishes on 200 and 300 Series, maraging, and precipitation-hardening alloys.

A2.4 Hardenable 400 Series, maraging, and precipitation-hardening alloys in the hardened condition are subject to hydrogen embrittlement or intergranular attack when exposed to acids that can cause the generation of hydrogen on the item being cleaned. Cleaning by mechanical methods or other chemical methods is recommended. If acid treatment is unavoidable, parts should be heated at 250 and 300°F (121 to 149°C) for 24 h immediately following acid cleaning to drive off hydrogen and reduce susceptibility to embrittlement. The cleaning methods described in Parts II and III of Table A2.1 will not lead to the generation of hydrogen on hardenable 400 Series, maraging, and precipitation-hardening alloys in the hardened condition. Therefore, the post-cleaning thermal treatment is not required when these solutions are used for cleaning.

A2.5 Nitric-hydrofluoric acid solutions may intergranularly corrode certain alloys if they have been sensitized by improper heat treatment or by welding. Crevices resulting from intergranular attack can collect and concentrate halogens under service conditions or during cleaning or subsequent processing; these halogens can cause stress-corrosion cracking. Such alloys should not be cleaned with nitric-hydrofluoric acid solutions while in the sensitized condition. Consideration should be given to use of stabilized or low-carbon alloys if this kind of cleaning after welding is unavoidable.

A2.6 Severe pitting may result from prolonged exposure to certain acids if the solution becomes depleted or if the concentration of metallic salts becomes too high as a result of prolonged use of the solution; the concentration of iron should not exceed 2 weight %; take care to avoid overexposure.

A2.7 Nitric acid solutions are effective for removing free iron and other metallic contamination, but are not effective against scale, heavy deposits of corrosion products, temper films, or greasy or oily contaminants. Refer to Annex A1 for recommended practices where scale, heavy deposits of corrosion products, or heat-temper discoloration must be removed. Use conventional degreasing methods for removal of greasy or oil contaminants before any acid treatment.

A2.8 The citric acid-sodium nitrate treatment is the least hazardous for removal of free iron and other metallic contamination and light surface contamination. Spraying of the solution, as compared to immersion, tends to reduce cleaning time.

A2.9 Some latitude is permissible in adjusting acid concentrations, temperatures, and contact times; close control over these variables is essential once proper values have been established. Care must be taken to prevent acid depletion and buildup of metallic salt concentrations with prolonged use of solutions. In general, increasing the treatment temperature may accelerate or improve the overall cleaning action but it may also increase the risk of surface staining or damage.

A2.10 Materials must be degreased before acid treatment, and must be vigorously scrubbed with hot water and bristle brushes or with high-pressure water-jet immediately after completion of acid treatment; pH of final rinse water should be between 6 and 8 for most applications, or 6.5 to 7.5 for critical applications. To minimize staining, surfaces must not be permitted to dry between successive steps of the acid cleaning or passivation and rinsing procedure. Thorough drying should follow the final water rinse.

A2.11 Proper personnel protection, including face shields, rubber gloves, and rubber protective clothing, must be provided when handling acids and other corrosive chemicals. Adequate ventilation and strict personnel access controls must be maintained where such chemicals are being used.

A2.12 Pickling and cleaning or passivating solutions containing nitric acid will severely attack carbon steel items including the carbon steel in stainless steel-clad assemblies.

TABLE A2.1 Acid Cleaning of Stainless Steel

Alloy	Condition	Treatment			
		Code	Solution, Volume, %[A]	Temperature, °F (°C)	Time, Minutes
PART I—Cleaning with Nitric-Hydrofluoric Acid					

TABLE A2.1 *Continued*

Alloy	Condition	Treatment			
		Code	Solution, Volume, %[A]	Temperature, °F (°C)	Time, Minutes
Purpose —For use after descaling by mechanical or other chemical methods as a further treatment to remove residual particles of scale or products of chemical action (that is, smut), and to produce a uniform "white pickled" finish.					
200 and 300 Series, 400 Series containing Cr 16 % or more, and precipitation-hardening alloys (except free-machining alloys).	fully annealed only	D	HNO_3, 6–25 % plus HF, ½ to 8 %[B,C]	70–140 (21–60)	as necessary
Free-machining alloys, maraging alloys, and 400 Series containing less than Cr 16 %.	fully annealed only	E	HNO_3, 10 % plus HF, ½ to 1½ %[B,C]	70 (up to 140 with caution) (21–60)	1–2
PART II—Cleaning-Passivation with Nitric Acid Solution (see Specification A967 for passivation specifications)					
Purpose —For removal of soluble salts, corrosion products, and free iron and other metallic contamination resulting from handling, fabrication, or exposure to contaminated atmospheres (see 6.2.11)					
200 and 300 Series, 400 Series, precipitation hardening and maraging alloys containing Cr 16 % or more (except free-machining alloys).[D]	annealed, cold-rolled, thermally hardened, or work-hardened, with dull or nonreflective surfaces	F	HNO_3 20–50 %	120–160 (49–71) 70–100 (21–38)	10–30 30–60[C]
Same[D]	annealed, cold-rolled, thermally hardened, or work-hardened with bright-machined or polished surfaces	G	HNO_3 20–40 % plus $Na_2Cr_2O_7 \cdot 2H_2O$, 2–6 weight %	120–155 (49–69) 70–100† (21–38)	10–30 30–60[C]
400 Series, maraging and precipitation-hardening alloys containing less than Cr 16 % high-carbon-straight Cr alloys (except free-machining alloys).[D]	annealed or hardened with dull or non-reflective surfaces	H	HNO_3, 20–50 %	110–130 (43–54) 70–100 (21–38)	20–30 60
Same[D]	annealed or hardened with bright machined or polished surfaces	I[E]	HNO_3 20–25 % plus $Na_2Cr_2O_7 \cdot 2H_2O$, 2–6 weight %	120–130 (49–54) 70–100 (21–38)	15–30 30–60
200, 300, and 400 Series free-machining alloys.[D]	annealed or hardened, with bright-machined or polished surfaces	J[E]	HNO_3, 20–50 % plus $Na_2Cr_2O_7 \cdot 2H_2O$, 2–6 weight %[F]	70–120 (21–49)	25–40
Same[D]	same	K[G]	HNO_3, 1–2 % plus $Na_2Cr_2O_7 \cdot 2H_2O$, 1–5, weight %	120–140 (49–60)	10
Same[D]	same	L[E]	HNO_3, 12 % plus $CuSO_4 \cdot 5H_2O$, 4 weight %	120–140 (49–60)	10
Special free-machining 400 Series alloys with more than Mn 1.25 % or more than S 0.40 %[D]	annealed or hardened with bright-machined or polished surfaces	M[E]	HNO_3, 40–60 % plus $Na_2Cr_2O_7 \cdot 2H_2O$, 2–6 weight %	120–160 (49–71)	20–30
PART III—Cleaning with Other Chemical Solutions					
	Purpose— General cleaning.				
200, 300, and 400 Series (except free-machining alloys), precipitation hardening and maraging alloys	fully annealed only	N	citric acid, 1 weight % plus, $NaNO_3$, 1 weight %	70 (21)	60
Same	same	O	ammonium citrate, 5–10 weight %	120–160 (49–71)	10–60
Assemblies of stainless and carbon steel (for example, heat exchanger with stainless steel tubes and carbon steel shell)	sensitized	P	inhibited solution of hydroxyacetic acid, 2 weight % and formic acid, 1 weight %	200 (93)	6 h
Same	same	Q	inhibited ammonia-neutralized solution of EDTA (ethylene-diamene-tetraacetic acid) followed by hot-water rinse and dip in solution of 10 ppm ammonium hydroxide plus 100 ppm hydrazine	up to 250 (121)	6 h

[A] Solution prepared from reagents of following weight %: HNO_3, 67; HF, 70.

[B] For reasons of convenience and handling safety, commercial formulations containing fluoride salts may be found useful in place of HF for preparing nitric-hydrofluoric acid solutions.

[C] After acid cleaning and water rising, a caustic permanganate solution containing NaOH, 10 weight %, and $KMnO_4$, 4 weight %, 160 to 180°F (71 to 82°C), 5 to 60 min, may be used as a final dip for removal of smut, followed by thorough water rinsing and drying.

[D] The purchaser shall have the option of specifying in his purchase documents that all 400 Series ferritic or martensitic parts receive additional treatment as follows: Within 1 h after the water rinse following the specified passivation treatment, all parts shall be immersed in an aqueous solution containing 4 to 6 weight % $Na_2Cr_2O_7 \cdot 2H_2O$, at 140 to 160°F (60 to 71°C), 30 min. This immersion shall be followed by thorough rinsing with clean water. The parts then shall be thoroughly dried.
[E] See A2.2.
[F] If flash attack (clouding of stainless steel surface) occurs, a fresh (clean) passivating solution or a higher HNO_3 concentration will usually eliminate it.
[G] Shorter times may be acceptable where established by test and agreed upon by the purchaser.

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue, A380 – 99 (2005), that may impact the use of this standard. (Approved May 1, 2006.)

(1) Added new Section 1.5.
(2) Added Specification A967 to Section 2.
(3) Revised Table A2.1.
(4) Section A2.4 was revised.

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7.0 APPENDIX

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7.1 SOLID WIRE PROPERTIES

This section contains the Material Certifications for the solid wires tested in the Environmental Corrosion Test - Solid Wire in Section 7.3 and 7.4.

SOLID WIRE PROPERTIES - REFERENCE SAMPLES ONLY

See Section 7.3 Solid Wire Environmental Corrosion Test - These solid wire types were used in the initial Environmental Corrosion Test on Solid Wires in Section 7.3 to establish the optimim stainless steel alloy for this application.

Wire	Diameter	ASTM	Tensile Strength (PSI)
.044" SS Wire T-316L Annealed	0.0440"	ASTM E8	98,631
.044" SS Wire T-317 Annealed	0.04498"-0.04521"	ASTM E8	102,478
.044" SS Wire T-321 Annealed	.0440"	ASTM E8	103,900

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SOLID WIRE
USED IN TEST SOLID WIRE SAMPLES #1-7
Included in Section 7.3 Element Report # TOM002-21955B FINAL and
Section 7.4 Element Report #TOM002-21955C Final

FOR REFERENCE ONLY

TEST CERTIFICATE

CONTROL # 5326

.044” STAINLESS STEEL WIRE

T-316L ANNEALED

Diameter	Heat No.	Tensile
0.0440”	E120079	98,631 PSI

CHEMICAL ANALYSIS

C	Mn	Si	S	P	Cr	Ni
.018	.8500	.5150	.003	.028	16.83	11.11
Mo	**Cu**	**N**	**Co**	**Ti**	**Al**	**NB**
2.04	.3460	.0410	.237	.019	.007	.015

MADE IN USA

SOLID WIRE
USED IN TEST SAMPLES #8 - 14
Included in Section 7.3 Element Report # TOM002-21955B FINAL and
Section 7.4 Element Report #TOM002-21955C FINAL

FOR REFERENCE ONLY

TEST CERTIFICATE

CONTROL # 5323

.044" STAINLESS STEEL WIRE

T-317L ANNEALED

Diameter	Heat No.	Tensile
0.04498" – 0.04521"	530458	102,478 PSI

CHEMICAL ANALYSIS

Heat #	C	Cr	Cu	Mn	Mo
530458	0.01	18.7	0.11	1.5	3.54
	N	Ni	P	S	Si
	0.052	13.57	0.022	0.01	0.44

SOLID WIRE
USED IN TEST SAMPLES #15-21
Included in Section 7.3 Element Report # TOM002-21955B FINAL
Section 7.4 Element Report #TOM002-21955C FINAL

FOR REFERENCE ONLY

TOMAS OSINSKI DESIGN
P.O.# SAMPLE

TEST CERTIFICATE

CONTROL # __________

.0440" STAINLESS STEEL WIRE
T-321 ANNEALED

Diameter	Heat No.	Tensile	Yield	Elongation
0.0437"	131718	103,900 PSI	37.00 KSI	66.80%

CHEMICAL ANALYSIS

C	Si	Mn	P	S	Cr	Ni
0.048	0.70	1.72	0.013	0.001	17.53	9.80
Mo	**Co**	**Cu**	**N**	**Al**	**Ti**	
0.01	0.03	0.15	0.027	0.02	0.26	

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7.2 ENVIRONMENTAL SAMPLE MATRIX SOLID WIRES AND WELD JOINT

This section contains the Alloy Sample Matrix for reference. This matrix indicates the sample number, the specific properties of the sample, and the test procedures for each sample. The Environmental Corrosion Test Reports in Section 7.3 and 7.4 utilize the sample numbering system in this matrix.

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Eisenhower Memorial
Tapestry Engineering and Testing Data
7/8/2013

ALLOY SAMPLE MATRIX

Solid Wire and Weld Joint Samples

		Sample Intent				Weld Settings - 2500 Machine								
Sample #	Sample Material	Control Sample	Test Sample	Descaled**	Salt Fog Test***	Argon Shield during weld	Power - Voltage (V)	Pressure (lbs)	Frequency	T - Hold Time (ms)	Duty Cycle	R1-Ramp (ms)	R2-Ramp (ms)	Documentation Process
Step 1 - New Weld Process Samples														
316L Alloy Samples														
1	316L Annealed, 044" Solid Wire Welded Cross Sample	X				Yes	10	20	9750	64	43	53	163	Record Sample- Keep intact for original reference, reserve.
2	316L Annealed, 044" Solid Wire Welded Cross Sample	X				Yes	10	20	9750	64	43	53	163	Sample mounted and etched per ASTM 262. Maintain Sample as comparison to sample #3.
3	316L Annealed, 044" Solid Wire Welded Cross Sample		X		X	Yes	10	20	9750	64	43	53	163	Sample mounted and etched per ASTM 262. Document. Compare to Control Sample #2.
4	316L Annealed, 044" Solid Wire Welded Cross Sample		X		X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
5	316L Annealed, 044" Solid Wire Welded Cross Sample		X		X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
6	316L Annealed, 044" Solid Wire Welded Cross Sample		X	X	X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
7	316L Annealed, 044" Solid Wire Welded Cross Sample		X	X	X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
317L Alloy Samples														
8	317L Annealed, 044" Solid Wire Welded Cross Sample	X				Yes	10	20	9750	64	43	53	163	Record Sample- Keep intact for original reference, reserve.
9	317L Annealed, 044" Solid Wire Welded Cross Sample	X				Yes	10	20	9750	64	43	53	163	Sample mounted and etched per ASTM 262. Maintain Sample as comparison to sample #10.
10	317L Annealed, 044" Solid Wire Welded Cross Sample		X		X	Yes	10	20	9750	64	43	53	163	Sample mounted and etched per ASTM 262. Document. Compare to Control Sample #9.
11	317L Annealed, 044" Solid Wire Welded Cross Sample		X		X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
12	317L Annealed, 044" Solid Wire Welded Cross Sample		X		X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
13	317L Annealed, 044" Solid Wire Welded Cross Sample		X	X	X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
14	317L Annealed, 044" Solid Wire Welded Cross Sample		X	X	X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
321 Alloy Samples														
15	321 Annealed, 044" Solid Wire Welded Cross Sample	X				Yes	10	20	9750	64	43	53	163	Record Sample- Keep intact for original reference, reserve.
16	321 Annealed, 044" Solid Wire Welded Cross Sample	X				Yes	10	20	9750	64	43	53	163	Sample mounted and etched per ASTM 262. Maintain Sample as comparison to sample #17.
17	321 Annealed, 044" Solid Wire Welded Cross Sample		X		X	Yes	10	20	9750	64	43	53	163	Sample mounted and etched per ASTM 262. Document. Compare to Control Sample #16.
18	321 Annealed, 044" Solid Wire Welded Cross Sample		X		X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
19	321 Annealed, 044" Solid Wire Welded Cross Sample		X		X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
20	321 Annealed, 044" Solid Wire Welded Cross Sample		X	X	X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.
21	321 Annealed, 044" Solid Wire Welded Cross Sample		X	X	X	Yes	10	20	9750	64	43	53	163	1) Provide Photographic Documentation of exterior surface weld area prior to Environmental Testing. 2) Provide Photographic Documentation of exterior surface weld area after Environmental Testing.

Notes

Descaled**	Performed per standard lab procedure for descaling material surface. Descaled using method Amibrite 100 (SOP 43.21 Rev1) at Element. See ASTM A 389, Standard Practice for Cleaning and Descaling Stainless Steel Parts, Equipment, and Systems for a general reference (not exact descaled process).
Salt Fog Test***	Performed per ASTM G85-11 Annex A4, Cycle A4.4.4.1. 1000 hours A 95+- 3 degrees, with constant spray of 5% +- 1 % wt NaCl, with in injection of SO2 gas every six hours to maintain pH of 2.5-3.2 environmental testing. All samples to be weighted with 2lbs during environmental testing. Carbon (Lamp Black) applied to all samples prior to 1000 hour environmental testing.

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7.3 ENVIRONMENTAL CORROSION TEST - SOLID WIRE

Included in this section:

- Element Materials Technology Report # TOM002-21955B Final *Titled Evaluation of 1000 Hour Salt Spray Tested Solid Wire Welds (Sunstone 2500 Equipment) Made from Type 316L, Type 317L and Type 321 Stainless Steel*
- Anachem Laboratories Test Report dated May 29, 2013

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Date: July 1, 2013
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Element Report #: TOM002-21955B Final

Evaluation of 1000 Hour Salt Spray Tested Solid Wire Welds (Sunstone 2500 Equipment) Made From Type 316L, Type 317L and Type 321 Stainless Steel

Prepared by:

Hugo A. Menendez, MS, P.E.
Department Manager, Failure Analysis, Metallurgist
Element Materials Technology – Huntington Beach

INTRODUCTION

Element personnel were asked to provide metallurgical laboratory and consulting services regarding the candidate stainless steels being considered for the Eisenhower Memorial Tapestry project. All samples provided and reviewed are listed in the Alloy Sample Matrix dated July 8th, 2013. Photographs of the solid wire resistance welded samples were taken before and after the 1000 hour environmental exposure, as well as after descale / passivation prior to the salt spray test. In order to keep the electronic file size of this document manageable, additional images not used in this report are presented in Element Report TOM002-04-04-21955C.

OBJECTIVE

Provide metallurgical support / consulting services relative to evaluating the performance variations, if any, between the three groups of welded wires being evaluated for use in the Eisenhower Memorial Tapestry.

SUMMARY & CONCLUSIONS

Based on the samples submitted and tests performed it is clear that the Type 316L and Type 317L materials performed significantly better than the Type 321 welded solid wire samples. High resolution digital stereo microscope photographs were taken of all the welded wire samples prior to submitting them directly to Anachem Laboratories, Inc, El Segundo, CA for environmental testing. High resolution digital images were taken of the weld joints in order to provide a one to one comparison of the samples before and after 1000 hours of acidified SO_2 salt spray testing.

It should be noted that the sulfur dioxide salt spray test performed as per ASTM G85 Annex A4 is much more aggressive than the standard salt spray test detailed in ASTM B117 due to the periodic introduction of $S0_2$ which results in a highly acidified salt fog environment (pH 2.5 and 3.2). In addition, the test procedure included coating all of the samples with lamp black, as well as applying a tensile stress in the form of a 2 lb weight.

Page 15 through page 23 show before and after digital stereo microscope pictures, presented in pairs, for the majority of the samples which were tested. None of the Type 316L or Type 317L samples exhibited obvious or discernable visual indications of pitting attack at the weld joints. No corrosion related weld failures occurred for the environmentally tested Type 316L and Type 317L samples.

Two of the samples provided (Sample #3 and Sample #10) were metallurgically evaluated for the possible presence of sensitization the results of which are presented on page 49 to page 52. The weld joints were cut, cast in a clear mounting media, hand ground to near centerline and polished to a metallurgical finish prior to be being tested and evaluated per ASTM Specification A262, Practice A. Neither of the two welds showed ditched structures indicating that sensitization was not present in either of the samples examined.

Several of the test samples were descaled / passivated in order to evaluate if chemical processing after welding would produce significantly notable increases in corrosion resistance. The descaled / passivated samples were photographed after descaling / passivation and then again after the 1000 hour salt spray test.

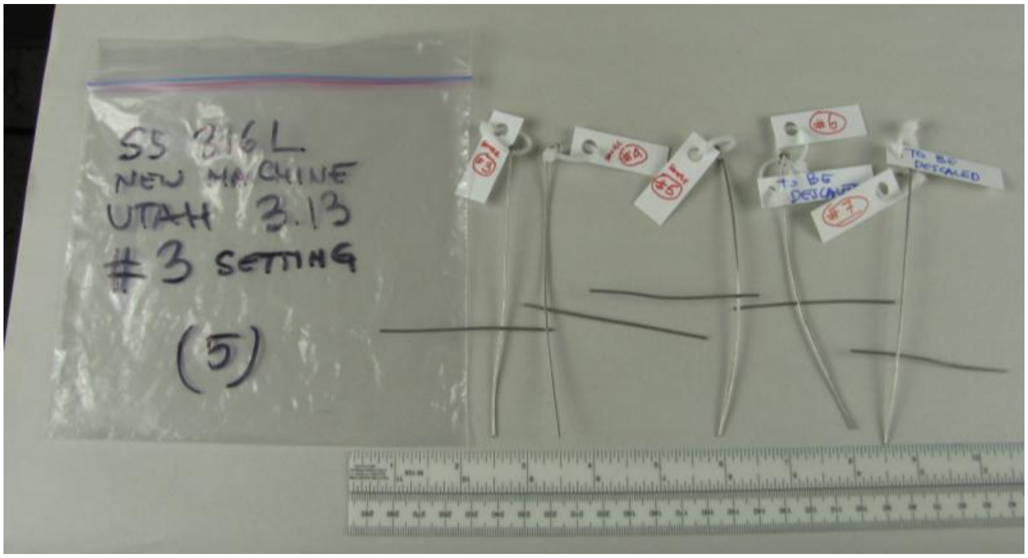
SUMMARY & CONCLUSIONS Continued:

The evaluations performed included visual inspection of the samples using a stereo microscope (7.5 – 75X magnifications), followed by further examinations using a super high resolution VHX-2000 digital stereo microscope. With the exception of the macro photographs all of the digital stereo images were taken with the VHX-2000 equipped with a 20 – 200X magnification lens. Sample # 4 and Sample #11 were further characterized using a Scanning Electron Microscope as detailed on page 29 to page 34. No clear indications of pitting attack were observed in the areas examined.

There did not appear to be any significant performance differences between the Type 316L and the Type 317L samples tested. Similarly, there did not appear to be any noticeable differences in performance between the descaled / passivated samples and the as-welded samples of the same alloys.

The Type 321 solid wire samples performed very poorly in the salt spray testing and reportedly started to exhibit red rust localized corrosion within a very short time period after having been placed into the salt fog chamber. Based on the unsatisfactory results obtained Alloy 321 is not recommended for the proposed application without first determining the reason for the poor corrosion resistance observed.

Macro, micro and SEM photographs detailing the laboratory observations are presented for review.



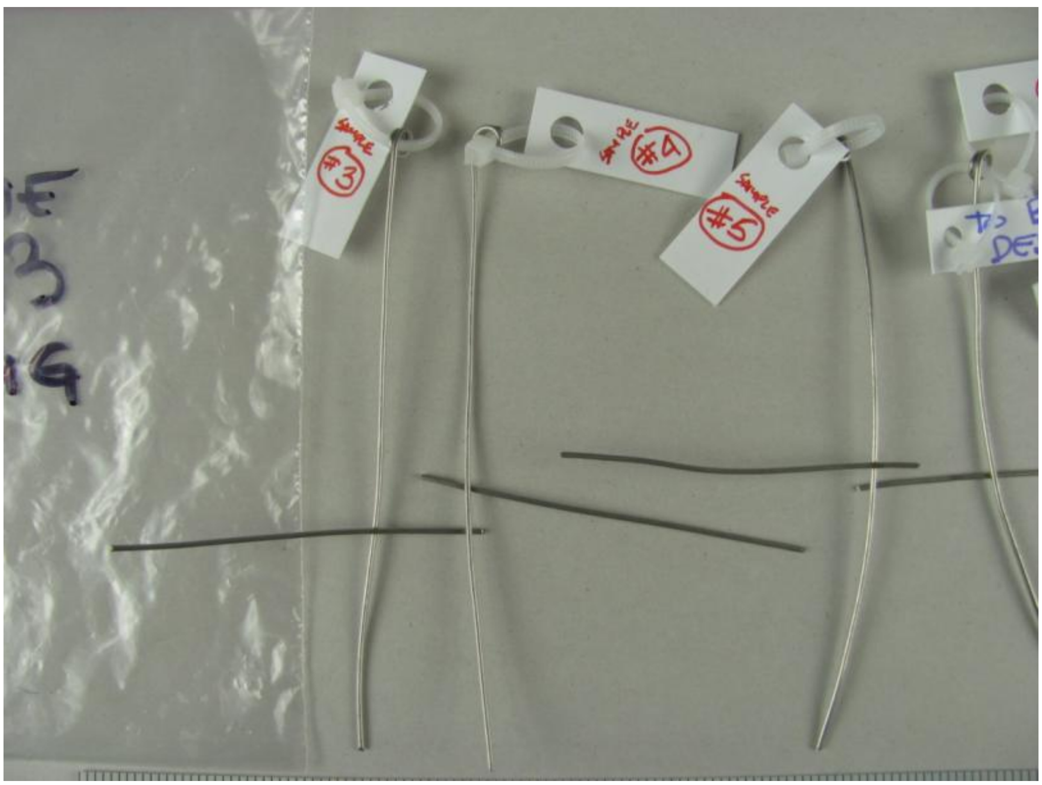


Figure 1 - Macro photographs showing the Type 316L solid wire weld samples submitted for evaluation, as-received prior to descale / passivation and salt spray testing. Samples #3, #4, #5, #6 and #7 are shown.

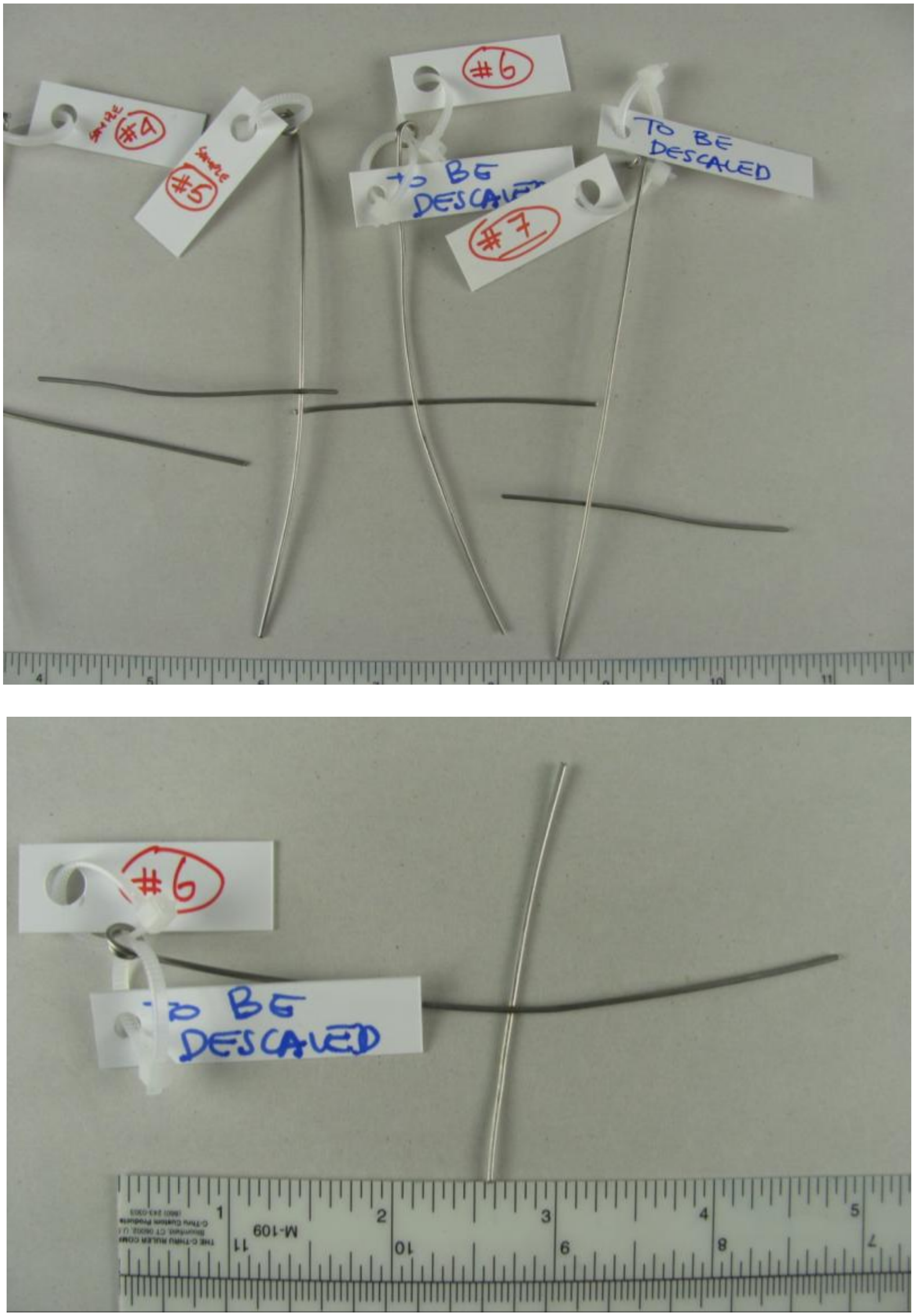


Figure 2 - Macro photographs showing some of the Type 316L solid wire weld samples and tags prior to descale / passivation and salt spray testing. Samples #4, #5, #6 and #7 are shown.

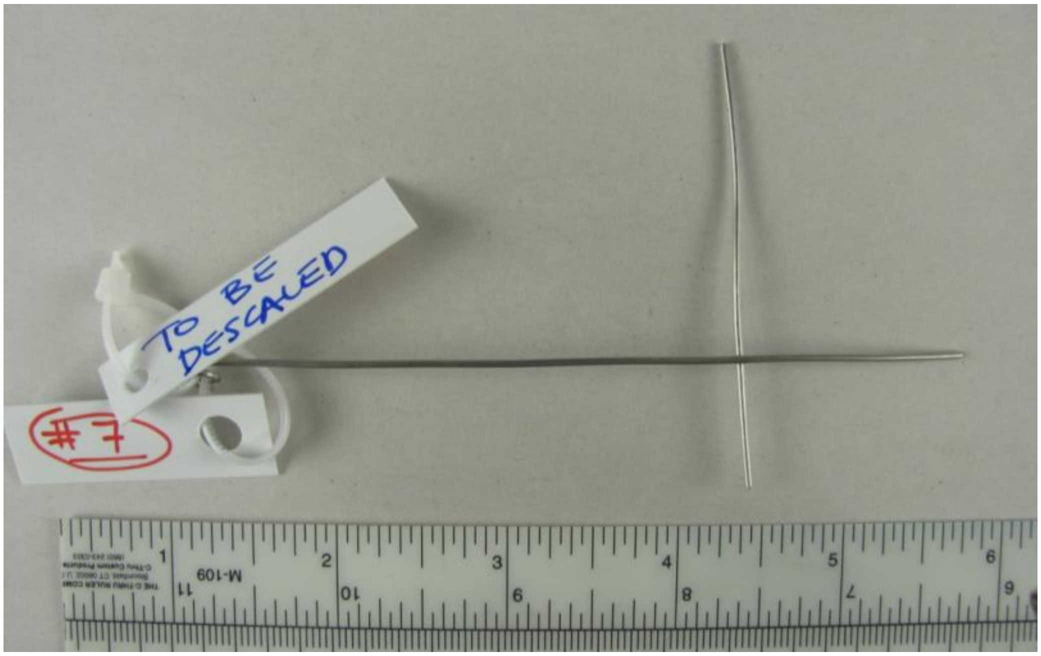


Figure 3 - Macro photograph showing one of the Type 316L solid wire weld samples to be descaled / passivated prior to salt spray testing. Sample #7 is shown.

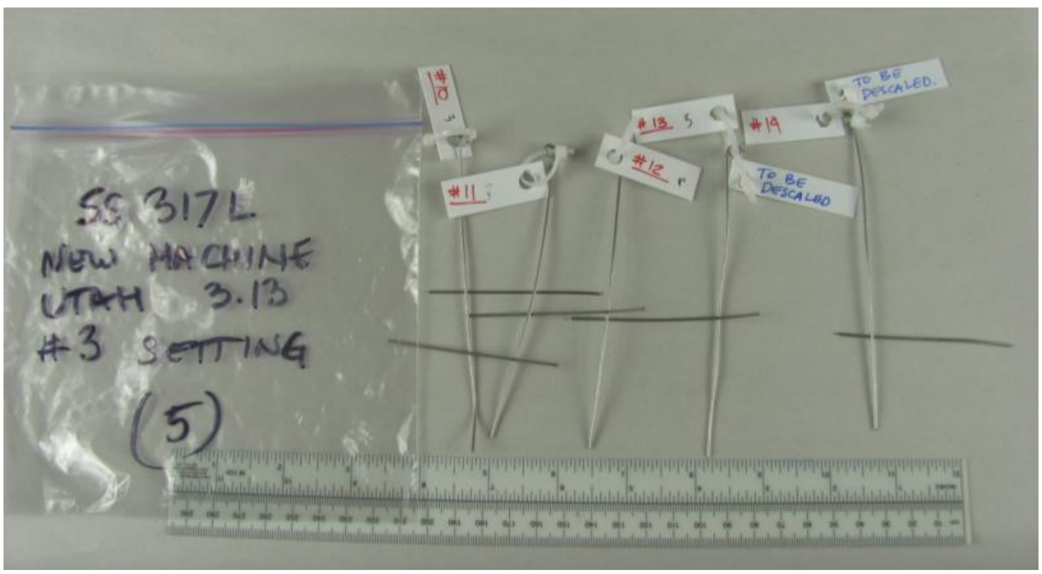
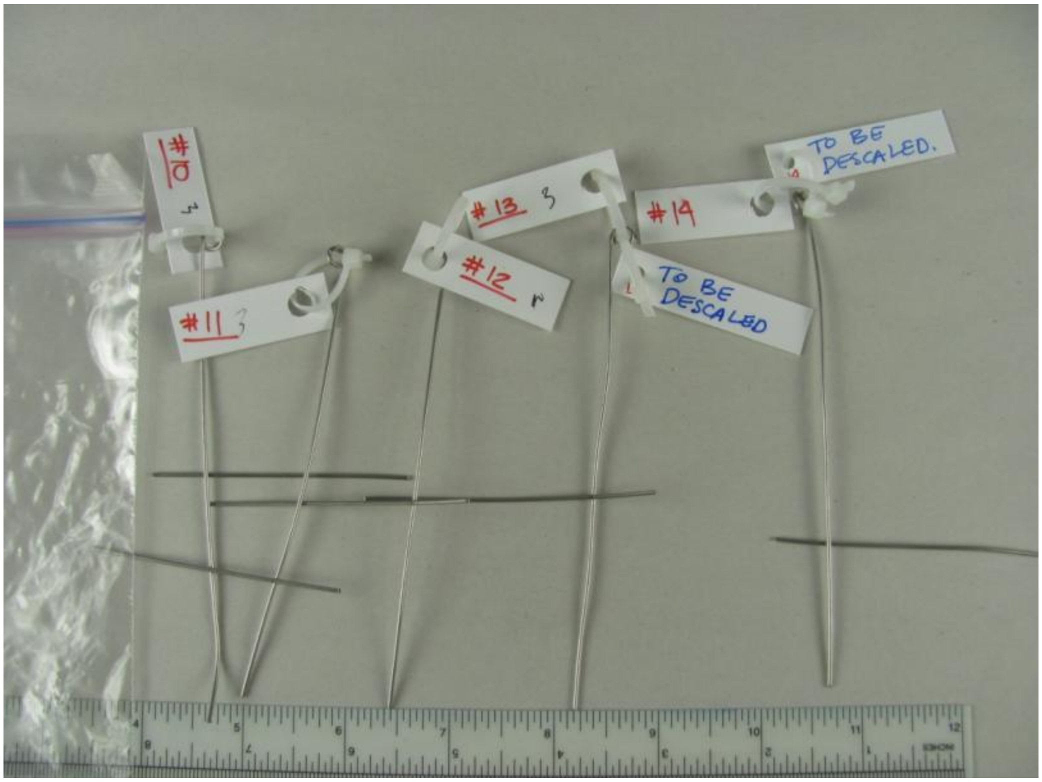


Figure 4 - Macro photographs showing the as-received Type 317L solid wire weld samples submitted for evaluation (prior to descale / passivation and salt spray testing). Samples #10, #11, #12, #13 and #14 are shown.



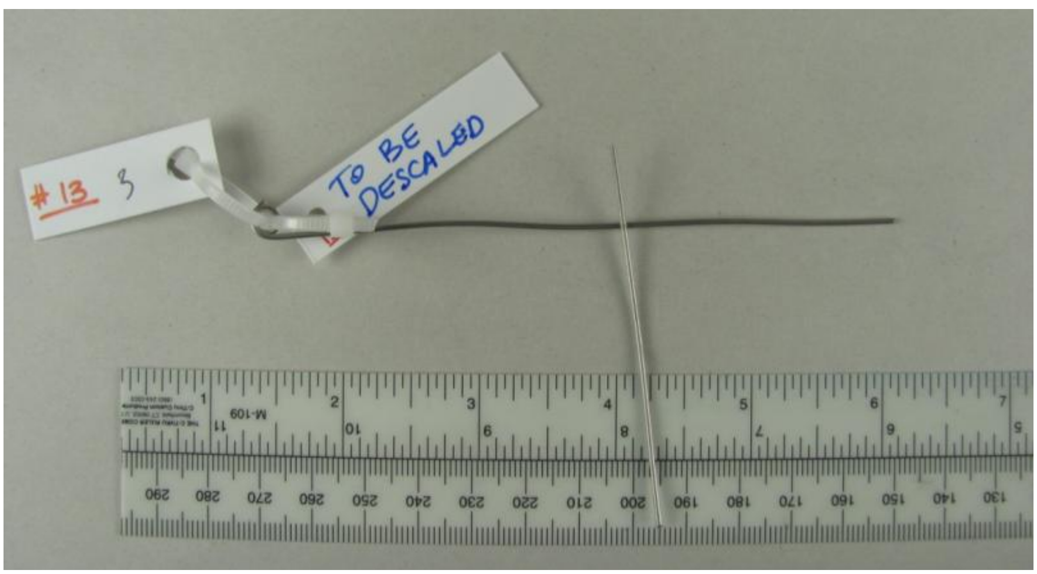


Figure 5 - Macro photographs showing some of the as-received Type 317L solid wire weld samples and tags prior to descale / passivation and salt spray testing.

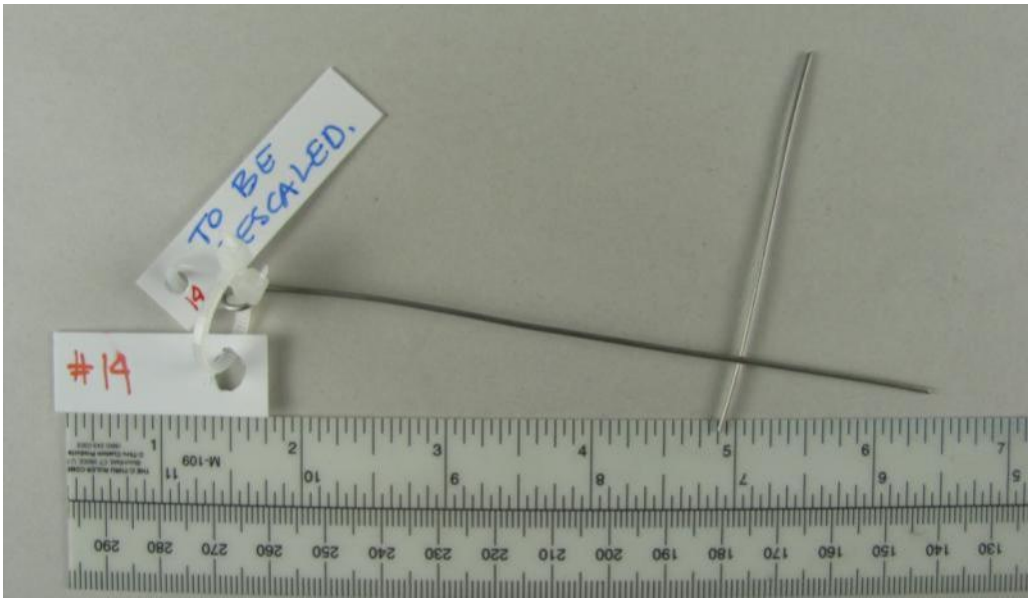


Figure 6 - Macro photograph showing Sample #14 (Type 317L) and its tags prior to descale / passivation and salt spray testing.

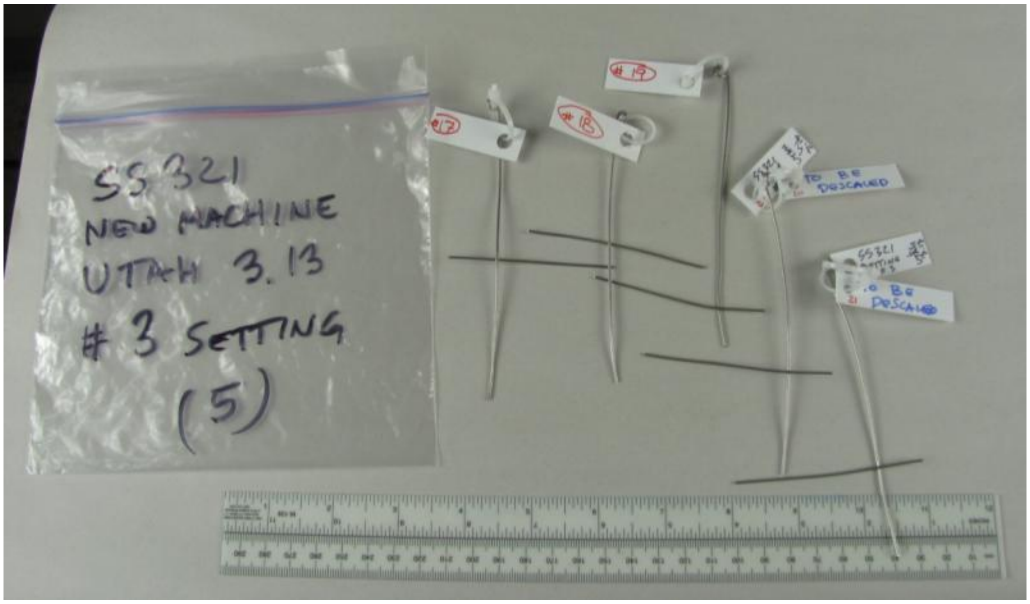


Figure 7 - Macro photographs showing the as-received appearance of the Type 321 solid wire weld samples prior to descale / passivation and salt spray testing. Samples #17, #18, #19, #20 and #21 are shown.

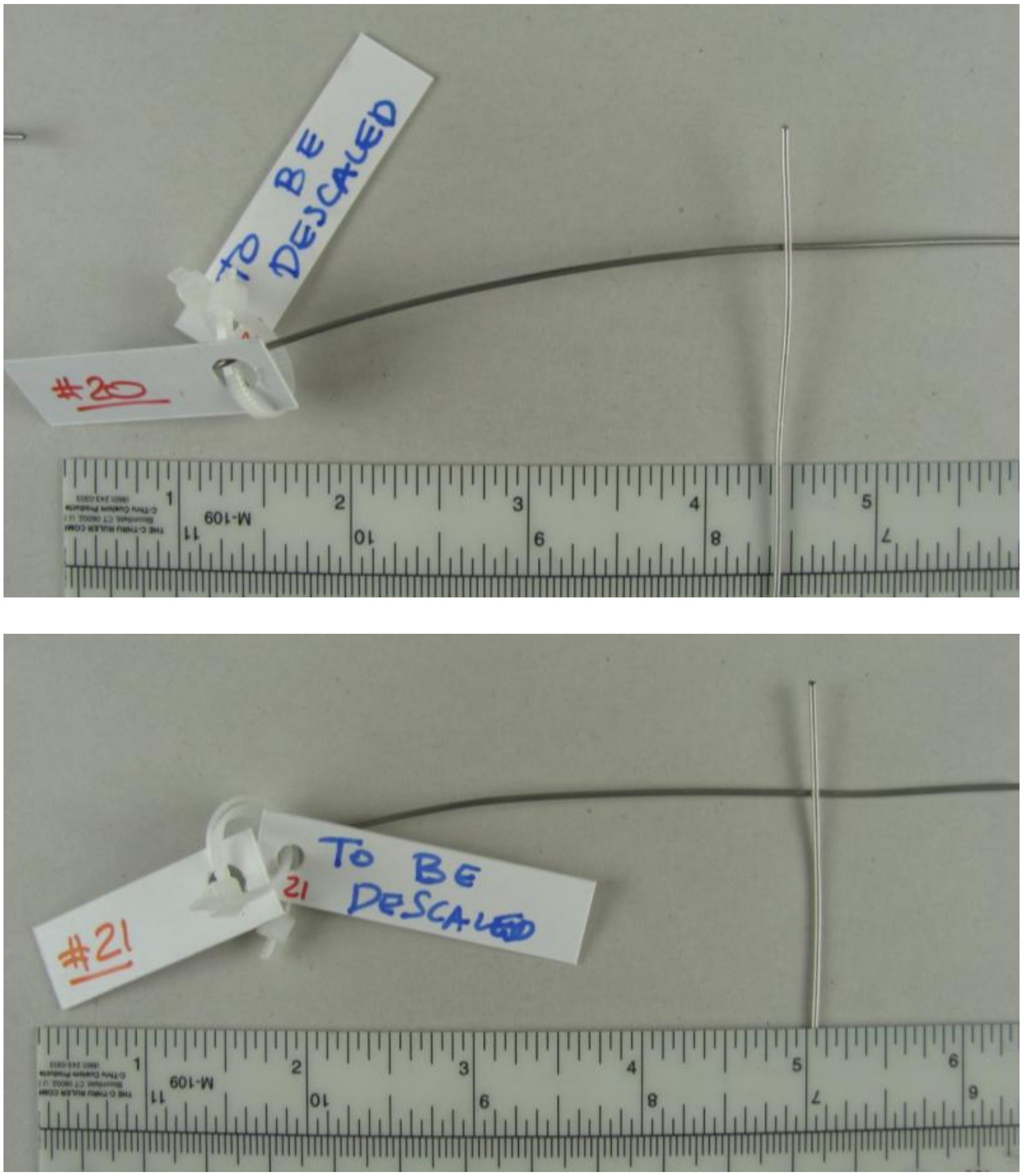


Figure 8 - Macro photographs showing the as-received appearance of the Type 321 solid wire weld samples prior to descale / passivation and salt spray testing. Sample #20 and Sample #21 are shown.

element

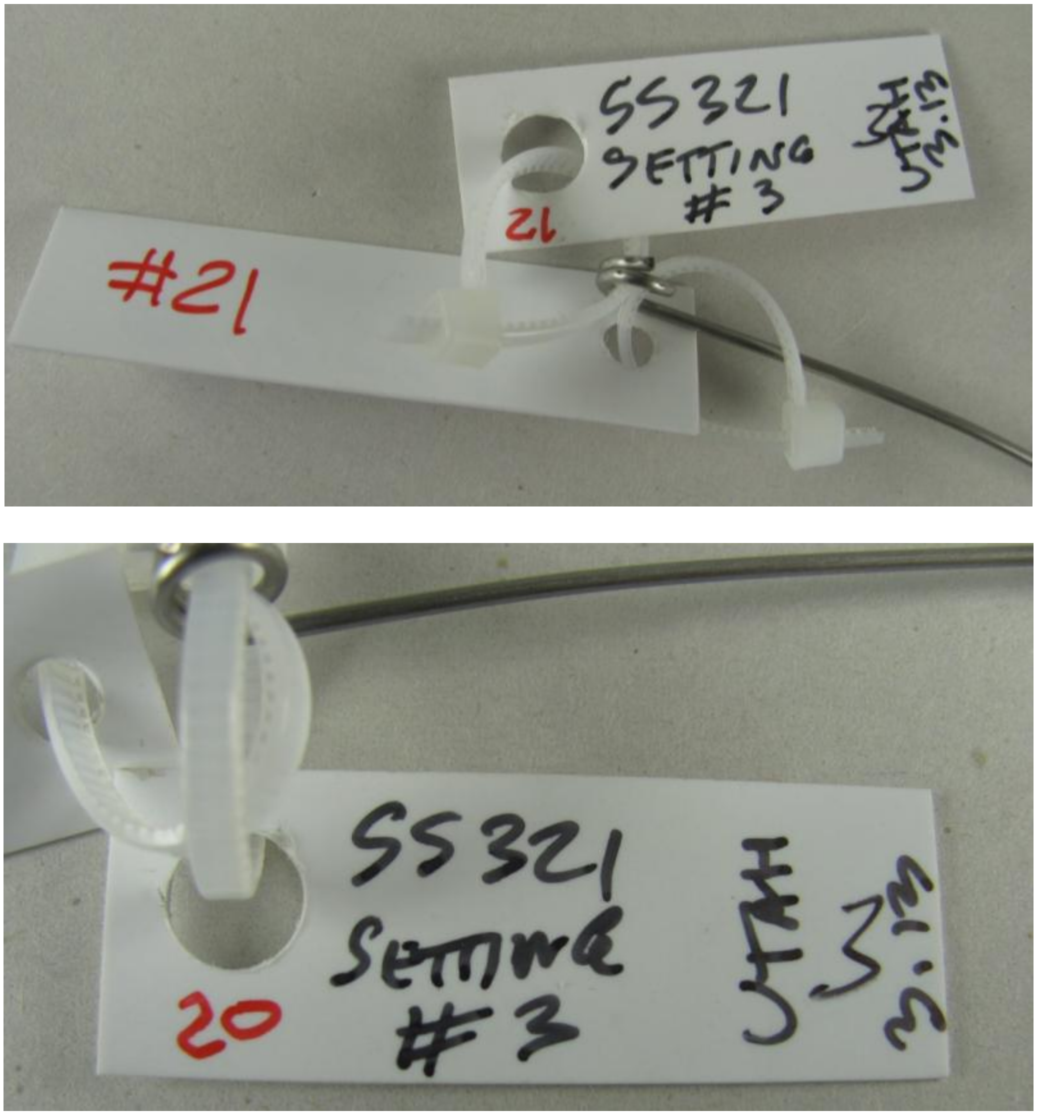


Figure 9 - Close-up photographs showing the tags on Sample #20 and Sample #21 (Type 321) which were specified as descale / passivation samples.

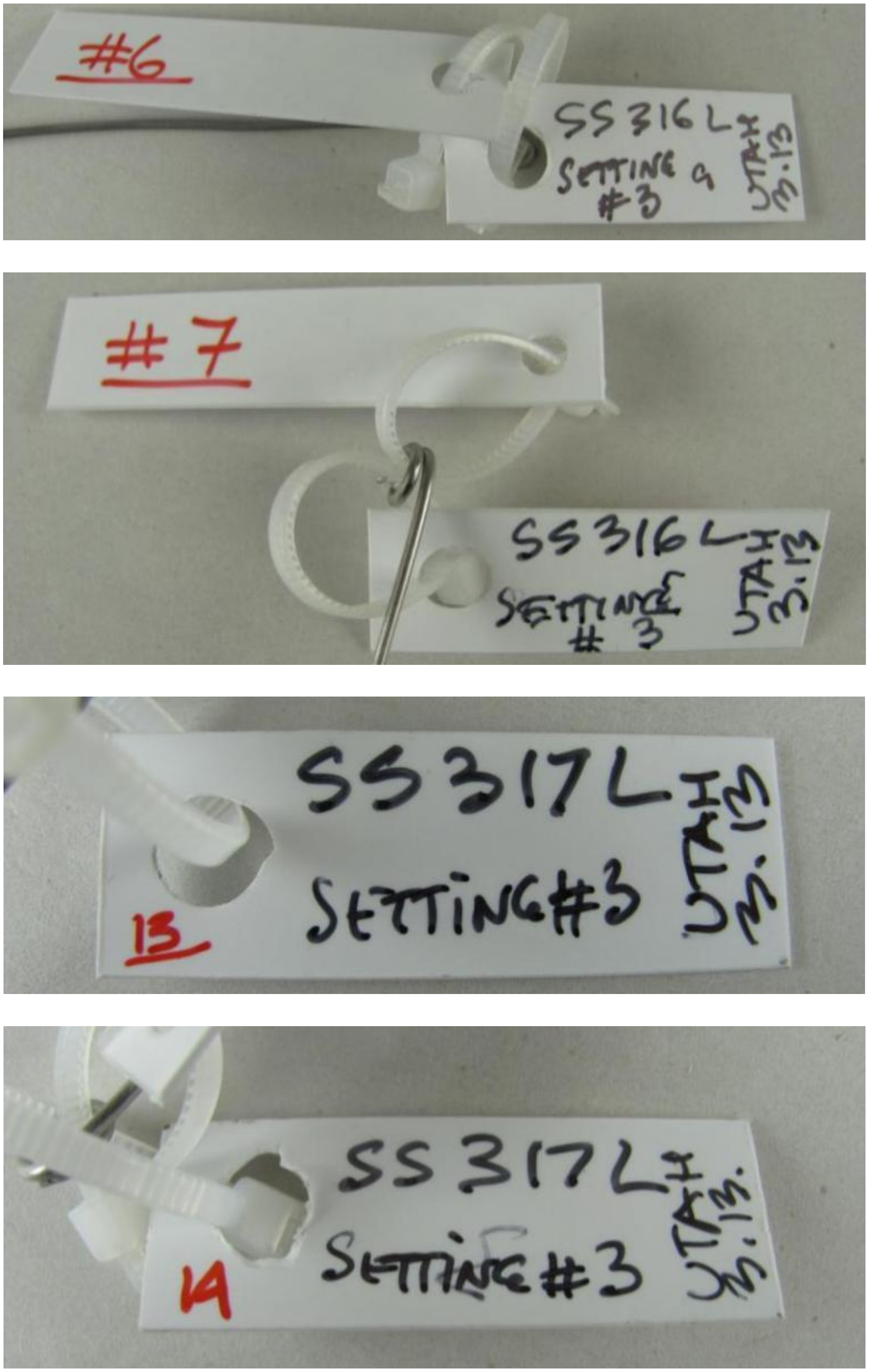


Figure 10 - Close-up photographs showing the tags on the #6, #7, #13 and #14 Type 316L solid wire weld samples.

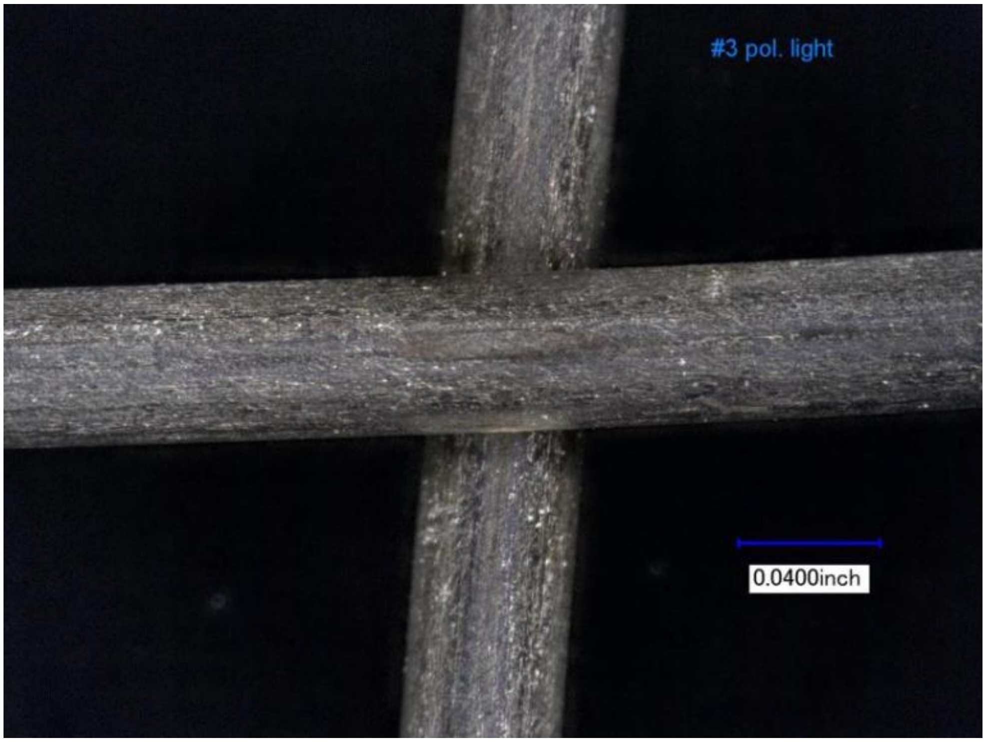
SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN:	None - test as received
CONDITION:	None - test as received
TESTING:	Coat samples with Lamp Black Rack samples and apply approximate 2-lb weight 1000 hours @ 95±3°F Constant spray of 5±1 %/wt Sodium Chloride Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN:	Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION:	Final evaluation by customer

Test procedure detailing the acidified SO_2 salt spray testing performed on the solid wire weld samples by Anachem Laboratories, Inc., El Segundo, CA.

Before (As-received) and After photographs of the Welded Solid Wire Type 316L and Type 317L Samples Following 1000 hours of Salt Spray Testing

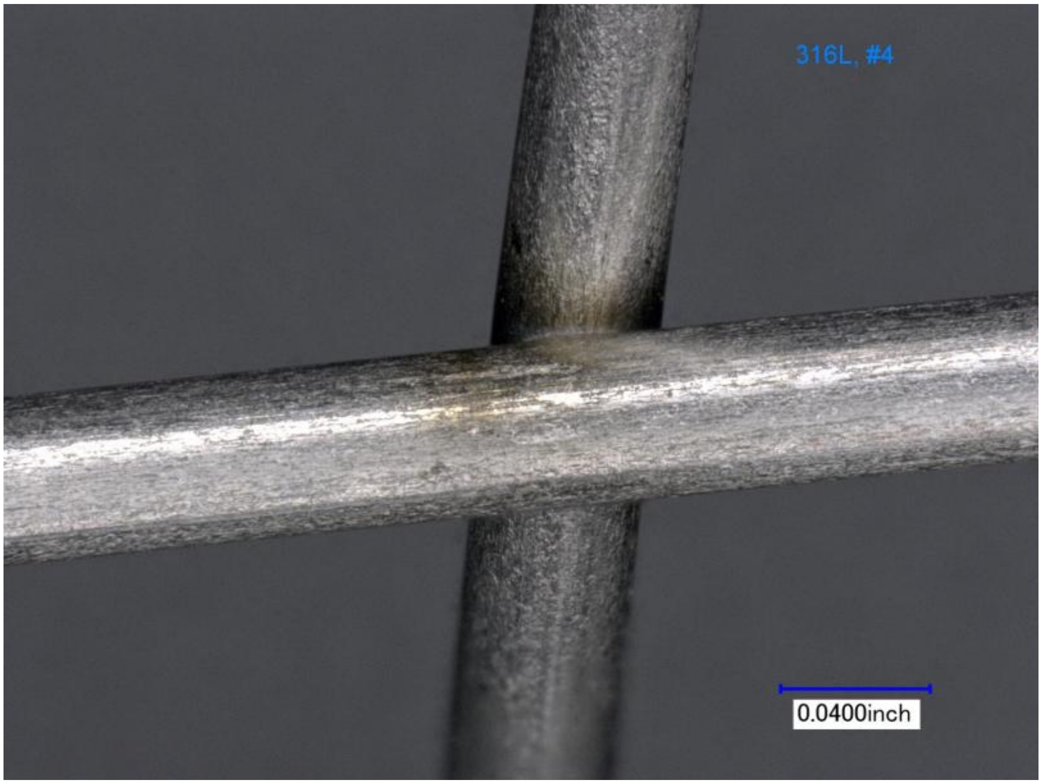
Page 15 through page 23 of the report present comparison photographs, i.e., before and after salt spray testing, of the Type 316L and Type 317L solid wire weld samples. Each page shows an as-received image (upper photograph) along with a corresponding image of the same sample taken after salt spray testing (lower photograph). None of the Type 316L or Type 317L samples showed obvious evidence of pitting in the area of the weld joints as illustrated by the after photographs. Many of the after images show residual black splotches or black patches which represent the lamp black applied to the samples as part of the salt spray testing procedures.



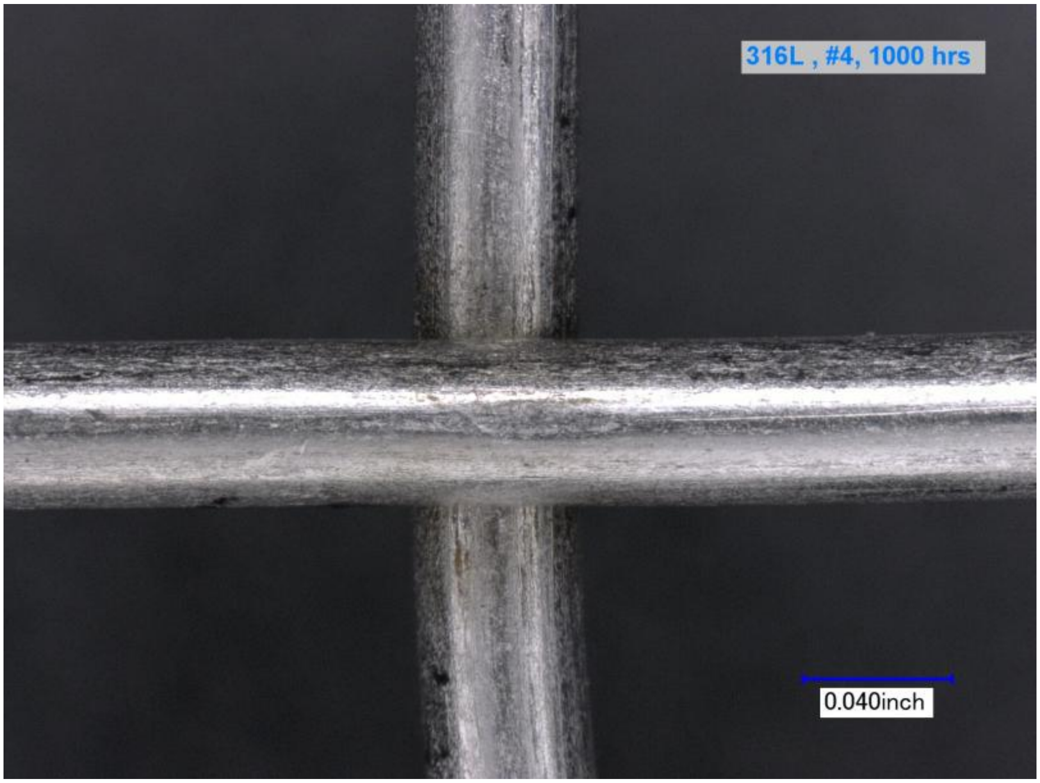
As-received Sample #3-1.jpg

After 1000 hours salt spray exposure Sample #3-1000hrs-1.jpg

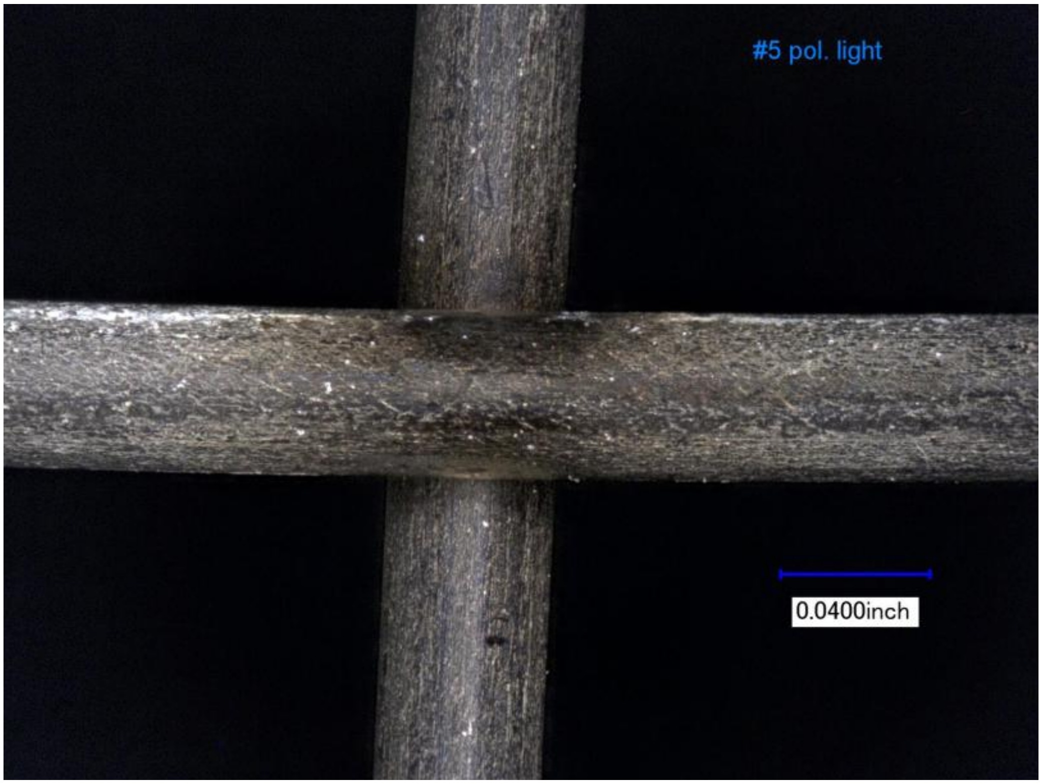
The black material in the lower photograph is residual lamp black that was applied to the sample as part of the salt spray testing performed.



As-received Sample #4-3.jpg

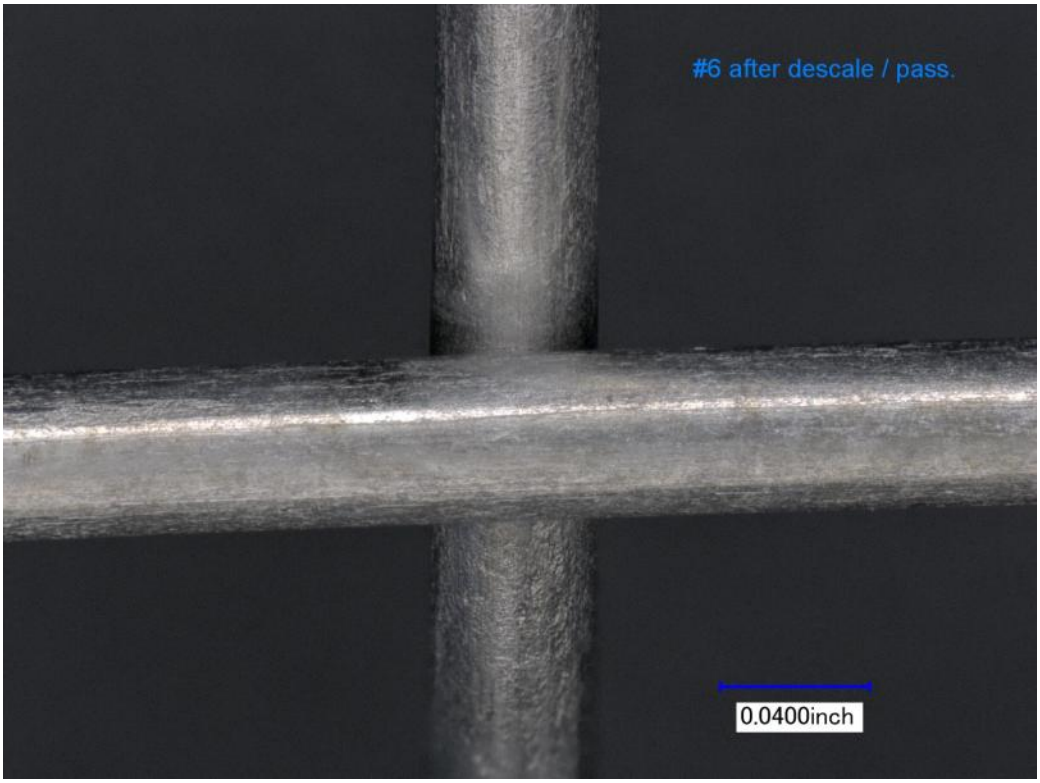


After 1000 hours salt spray exposure Sample #4-1000hrs-1.jpg

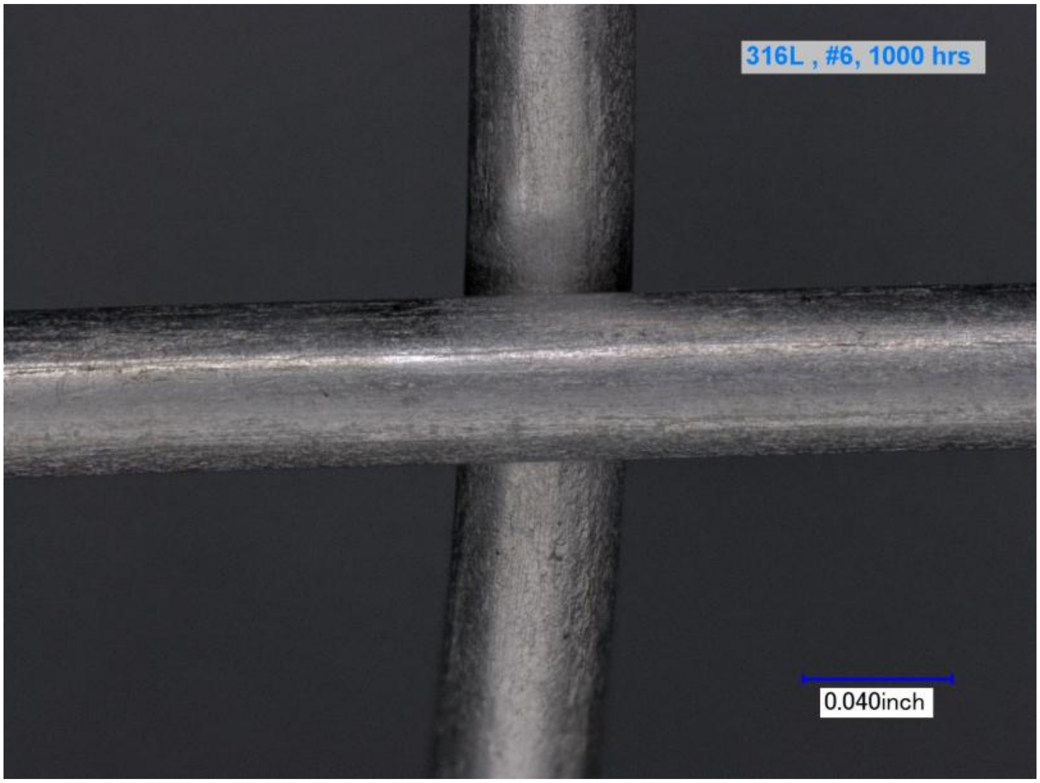


As-received, polarized light Sample #5-1.jpg

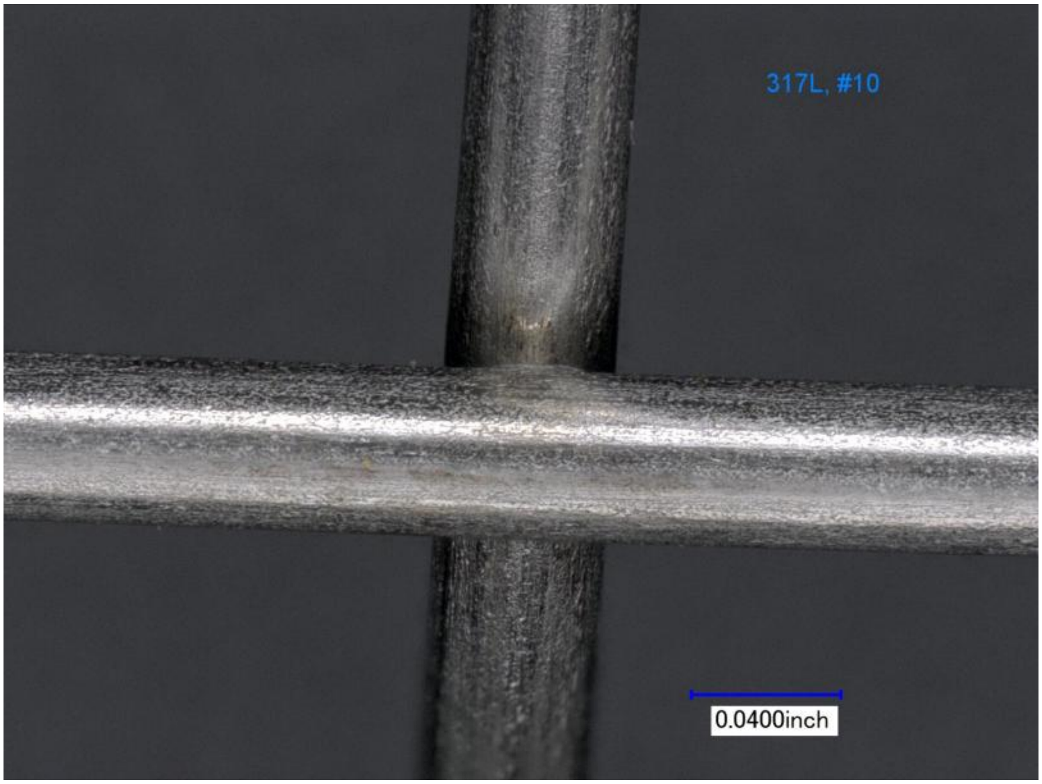
After 1000 hours salt spray exposure Sample #5-1000hrs-1.jpg



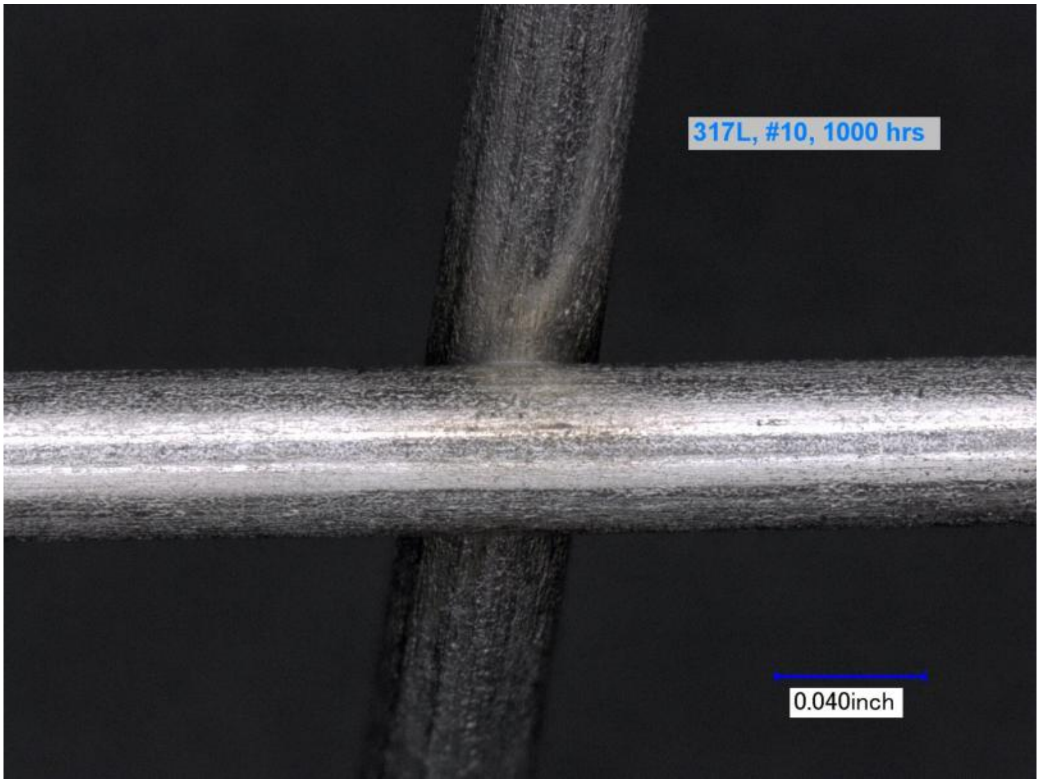
As-received Sample #6 after descale-2.jpg



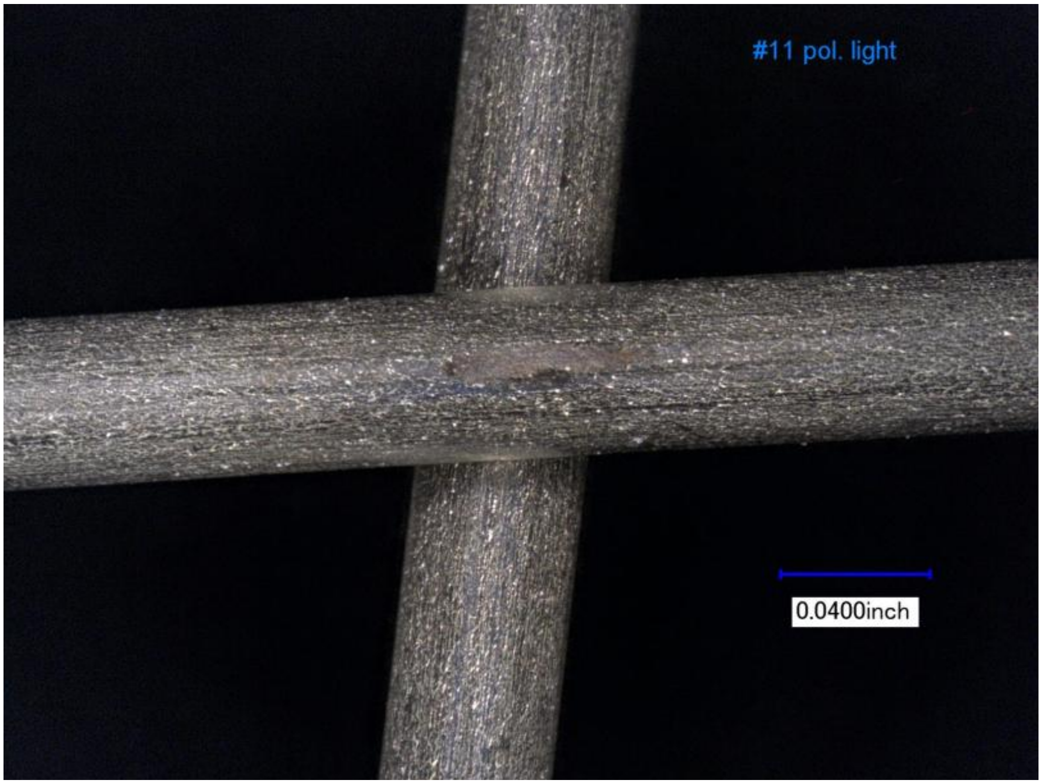
After 1000 hours salt spray exposure Sample #6-1000hrs-2.jpg



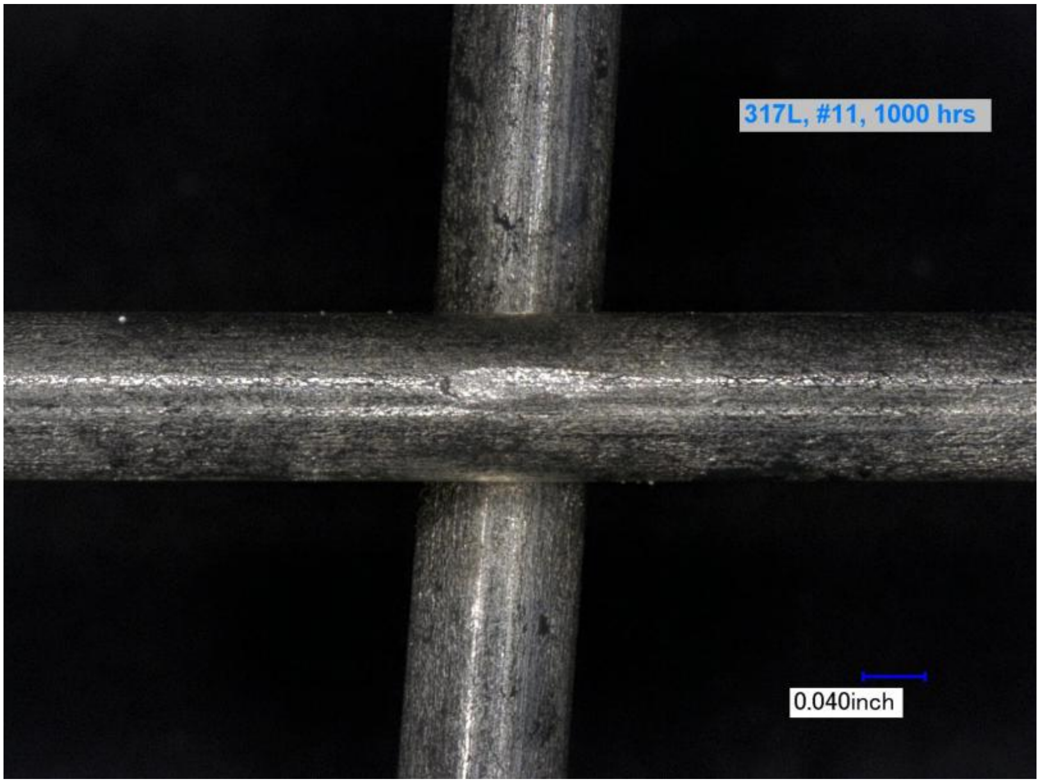
As-received Sample #10 - 3.jpg



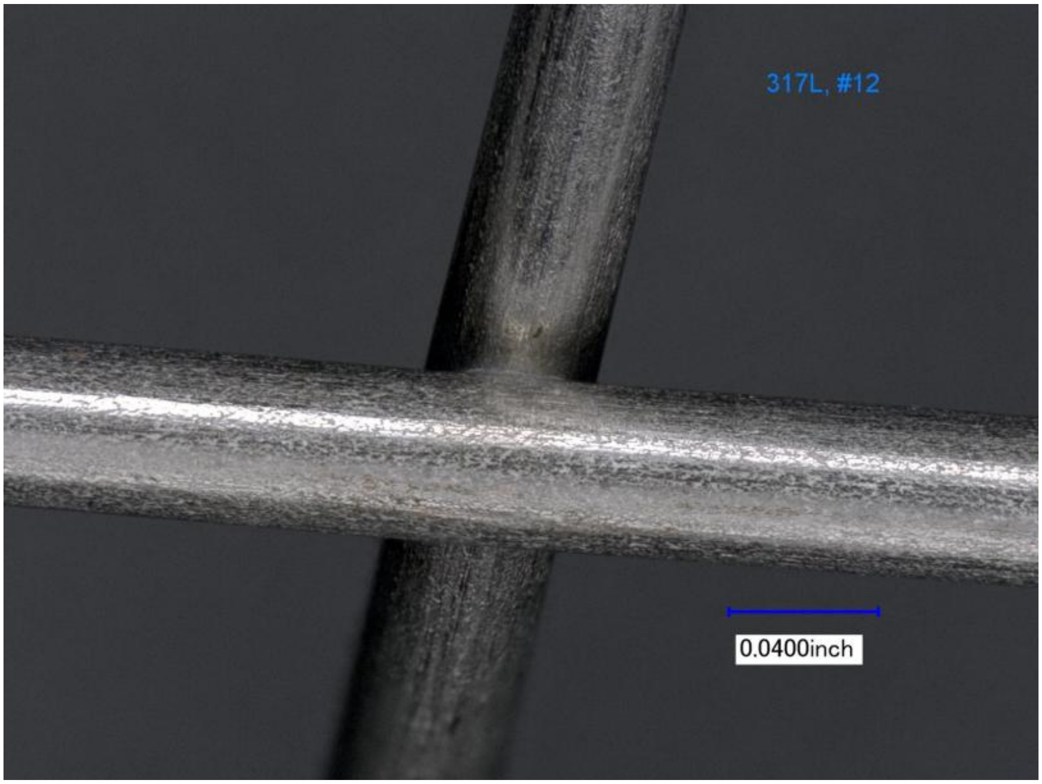
After 1000 hours salt spray exposure Sample #10-1000hrs-3.jpg



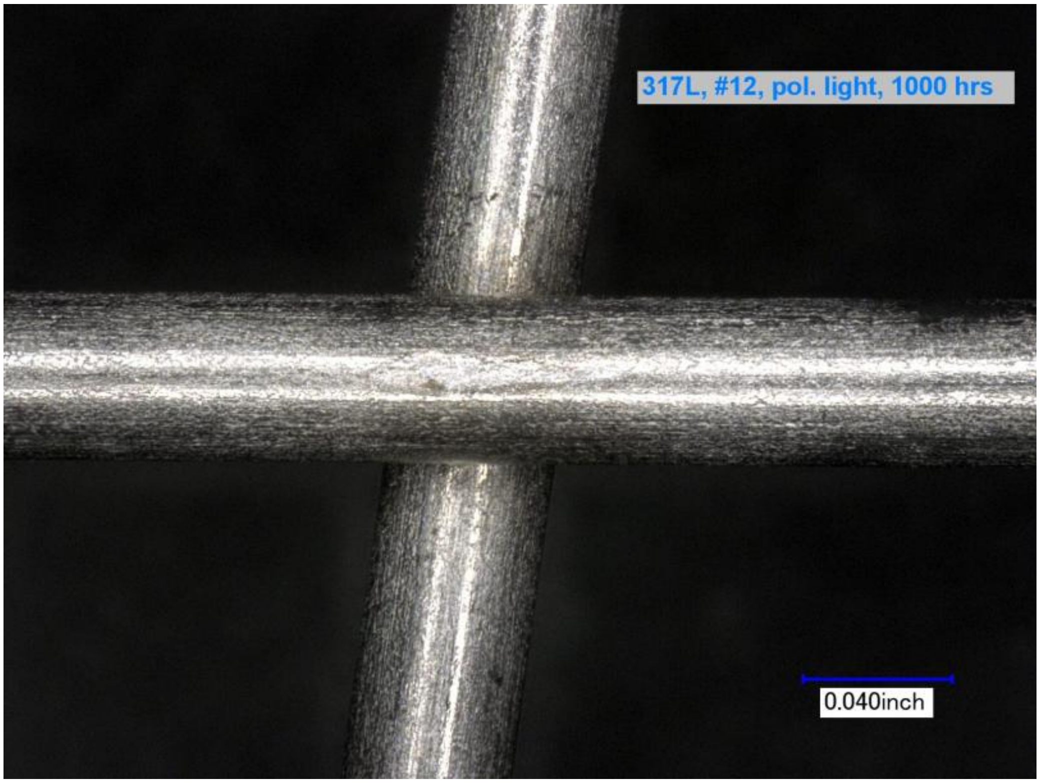
As-received Sample #11 - 1.jpg



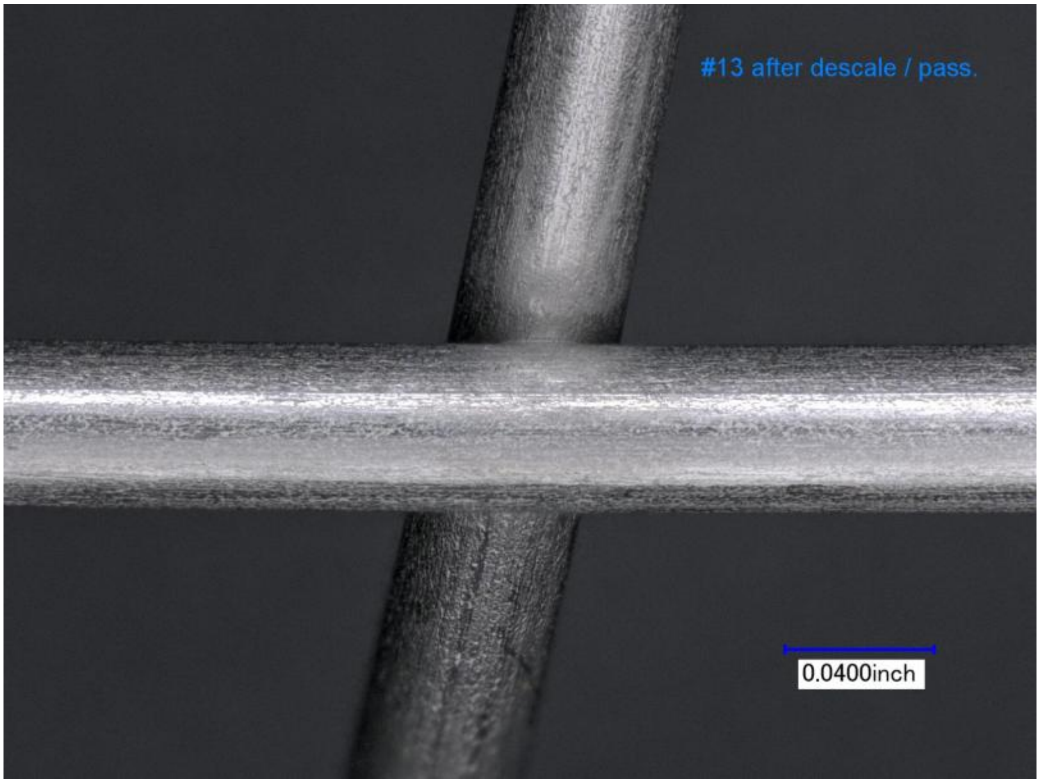
After 1000 hours salt spray exposure Sample #11-1000hrs-1.jpg



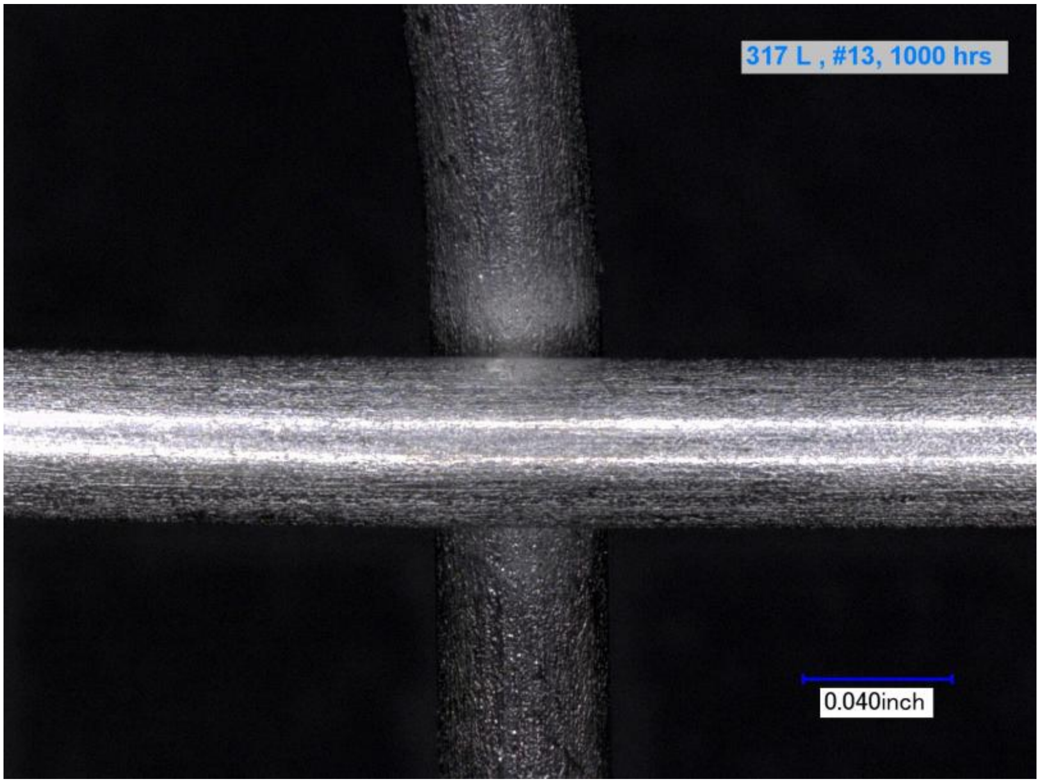
As-received Sample #12 - 3.jpg



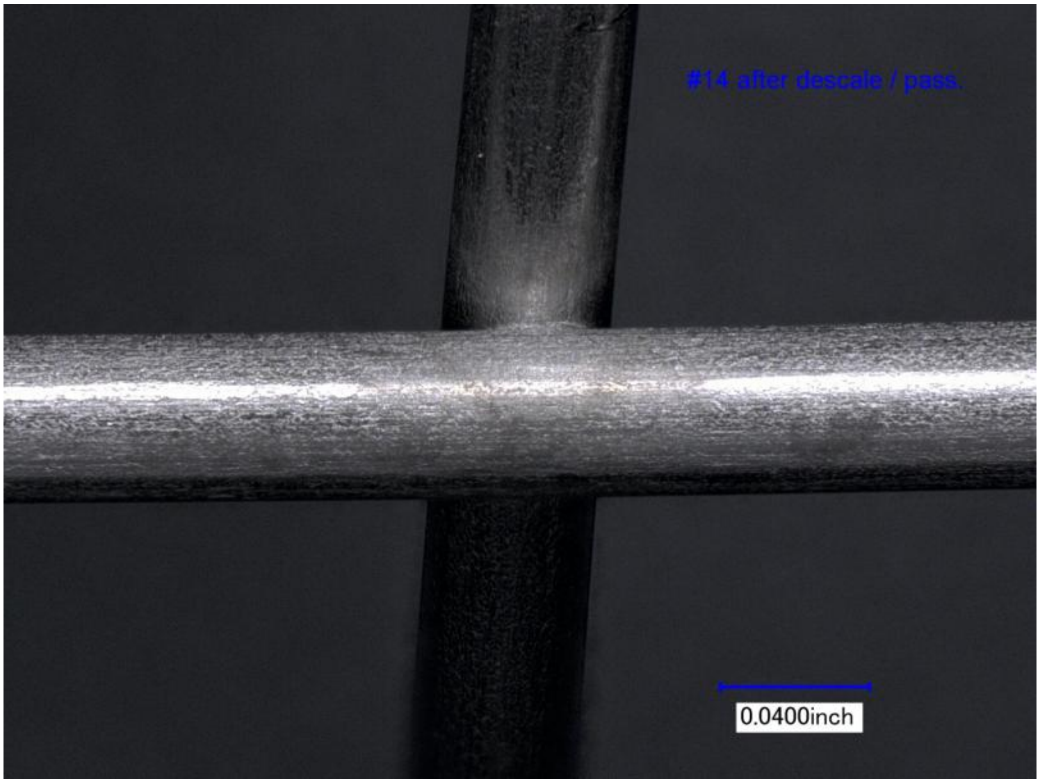
After 1000 hours salt spray exposure Sample #12-1000hrs-1.jpg



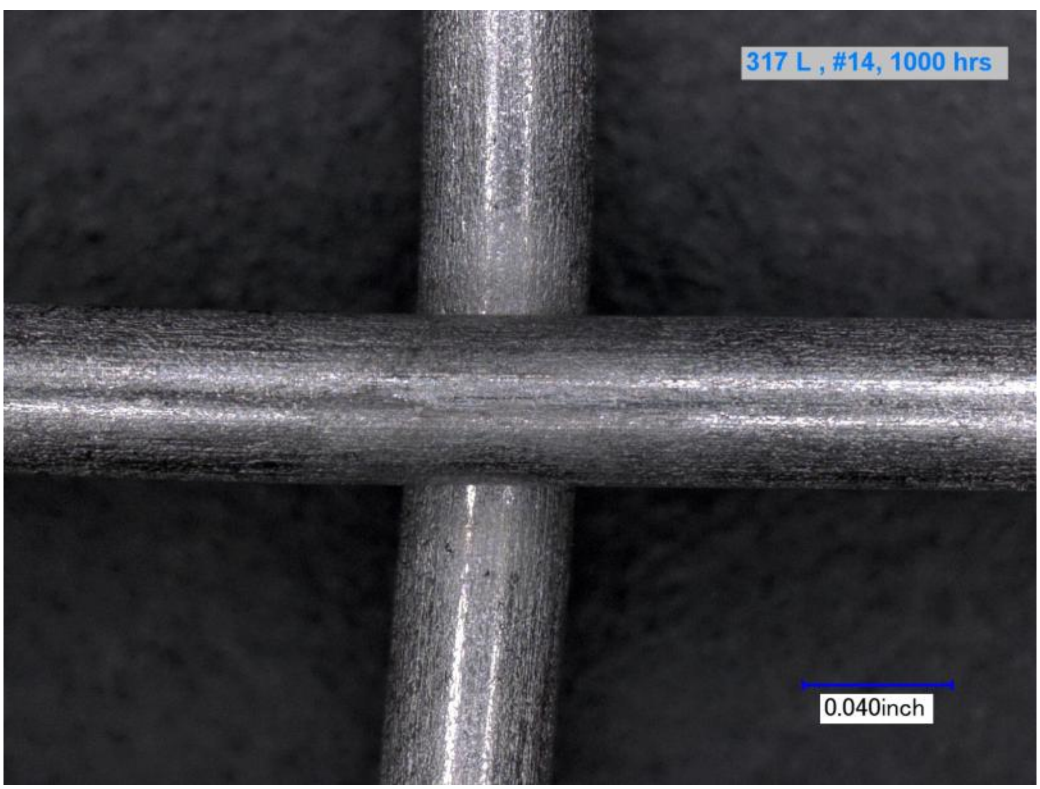
After descale / passivation Sample #13 after descale-2.jpg



After 1000 hours salt spray exposure Sample #13-1000hrs-2.jpg



After descale / passivation Sample #14 after descale-2.jpg



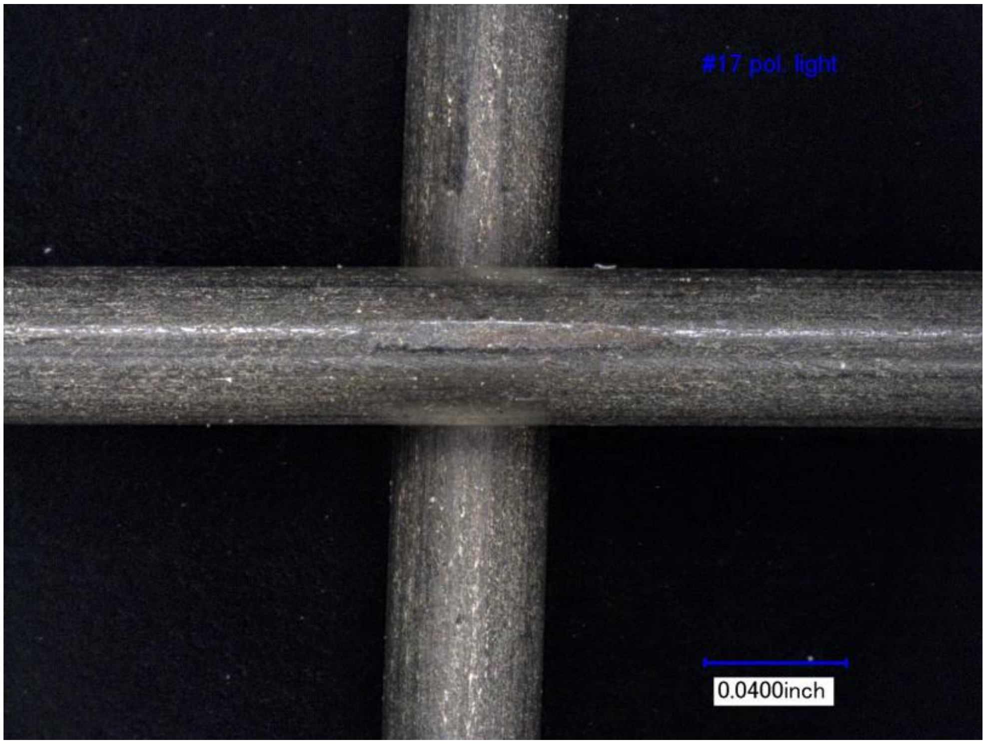
After 1000 hours salt spray exposure Sample #14-1000hrs-1.jpg

Before and After photographs of Several Type 321 Solid Wire Weld Samples

As mentioned in the Summary and Conclusions all of the Type 321 wire samples started to rust / corrode very shortly after being placed into the salt spray chamber according to the information provided. Representative photographs were taken as presented on page 25 to page 27, however not every sample was photographed.

Based on the unsatisfactory results obtained Alloy 321 is not recommended for the proposed application without determining the reason for the poor corrosion resistance observed.

Alloy 321 samples



As-received Sample #17 - 1.jpg

After salt spray testing Sample #17-354hrs.jpg

Based on the unsatisfactory results obtained, Alloy 321 is not recommended for the proposed application without determining the reason for the poor corrosion resistance observed.

As-received #18 - 1.jpg

After salt spray testing Sample #18-596 hrs.jpg

Based on the unsatisfactory results obtained, Alloy 321 is not recommended for the proposed application without determining the reason for the poor corrosion resistance observed.

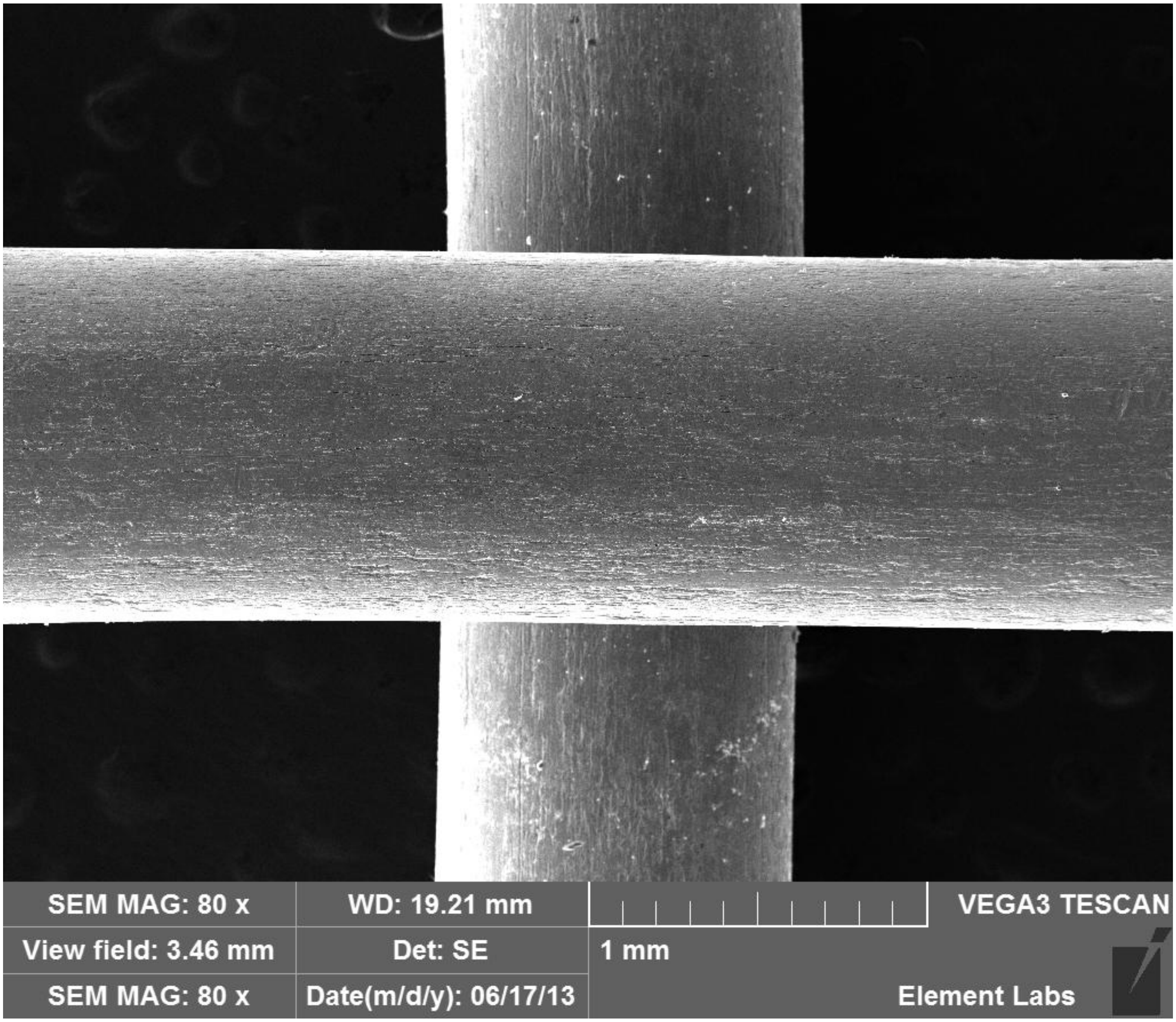
As-received Sample #19 - 1.jpg

After salt spray testing Sample #19-260 hrs.jpg

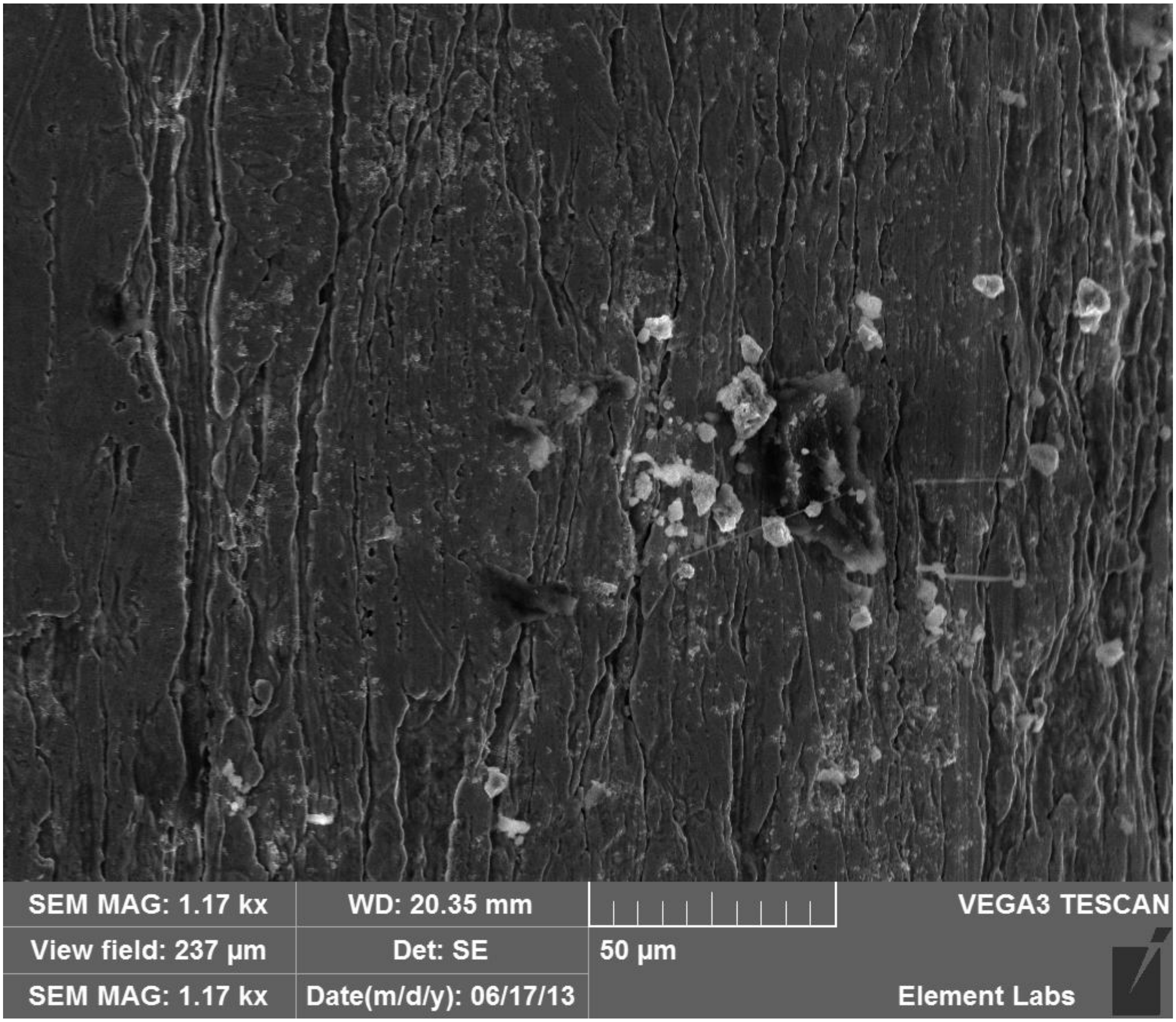
Based on the unsatisfactory results obtained, Alloy 321 is not recommended for the proposed application without determining the reason for the poor corrosion resistance observed.

SEM Images of Sample #4, Type 316L and Sample #11, Type 317L after 1000 hours of SO_2 Salt Spray Testing

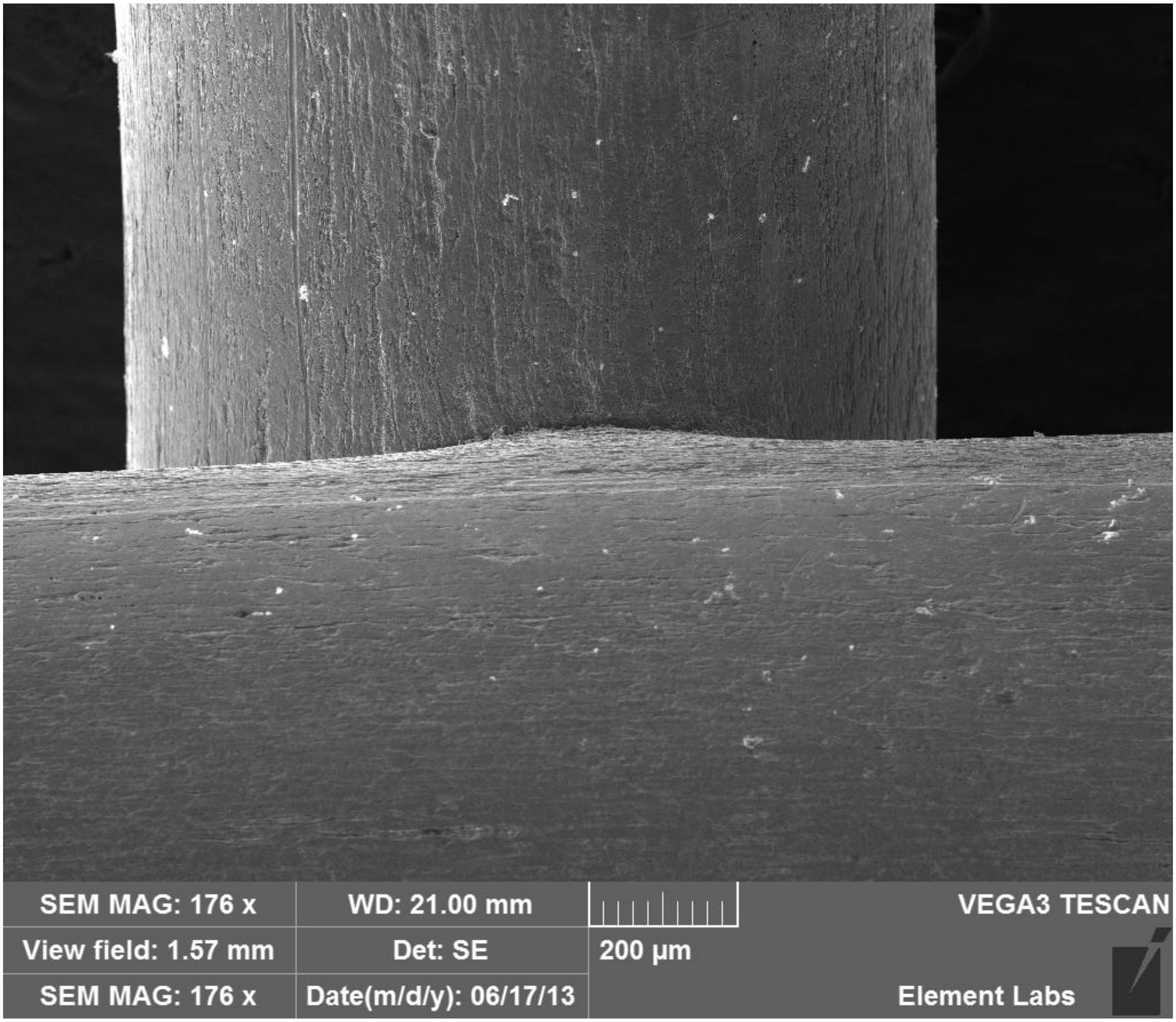
The SEM images show higher magnification views of the wire surfaces than the views presented in the digital stereo micrographs. No significant evidence of pitting attack was observed. Residual salt and lamp black can be seen in several of the images.



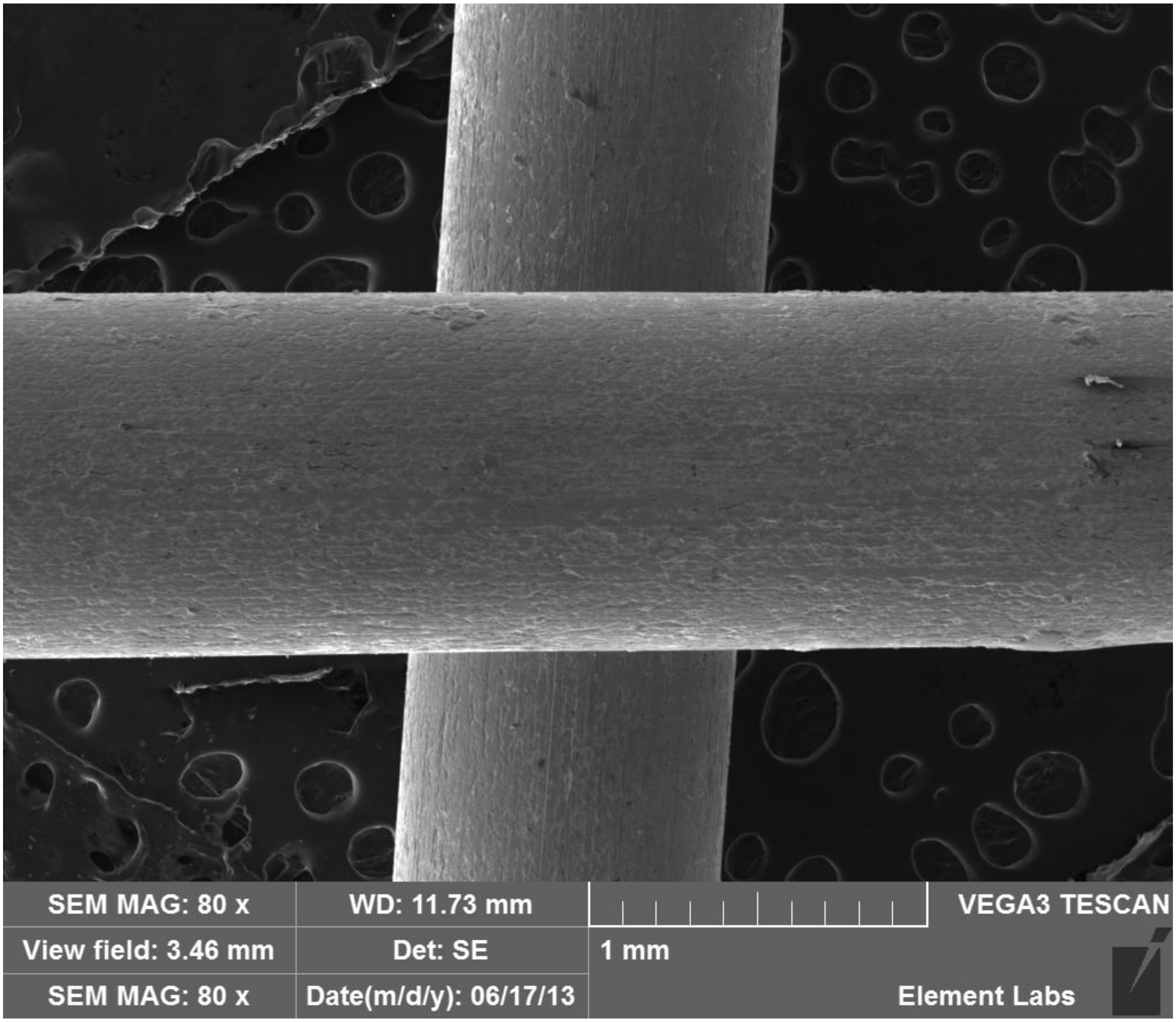
SEM image showing a low magnification view of Sample #4 (Type 316L) after 1000 hours of salt spray testing. One sample from each alloy group, excluding the Type 321 stainless steel samples, was examined using the Scanning Electron Microscope in order to provide a better level of inspection than available using stereo microscopy. The wire surfaces appeared relatively unaffected when examined at higher magnifications.



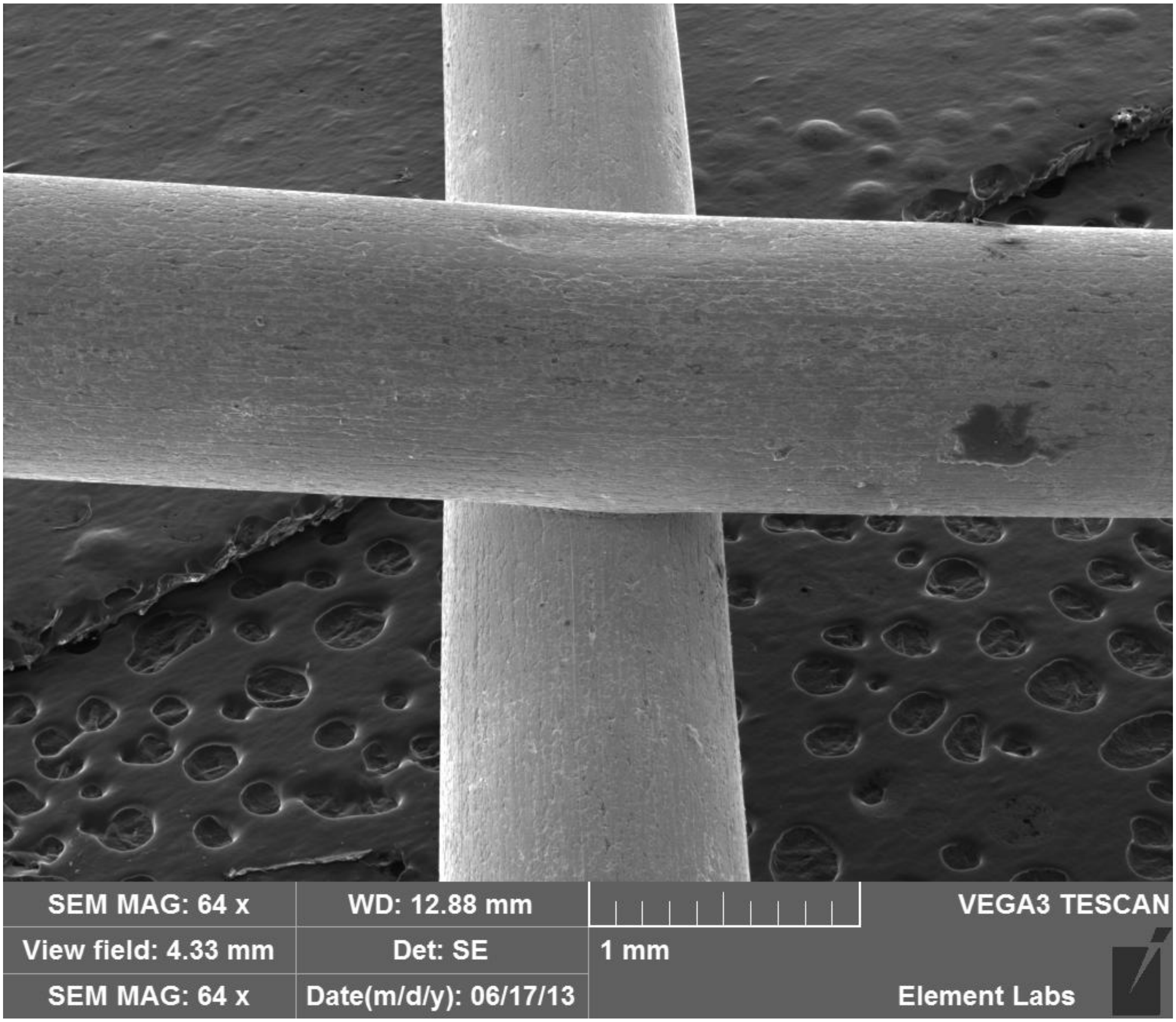
Higher magnification SEM image (1,117X magnification) showing an area on the wire surface from the weld joint shown in the previous image. Deposits (residual salt and carbon) are present on the wire surface however there are no obvious pits. The wire surface texture is typical of previously drawn austenitic wires previously examined by Element personnel.



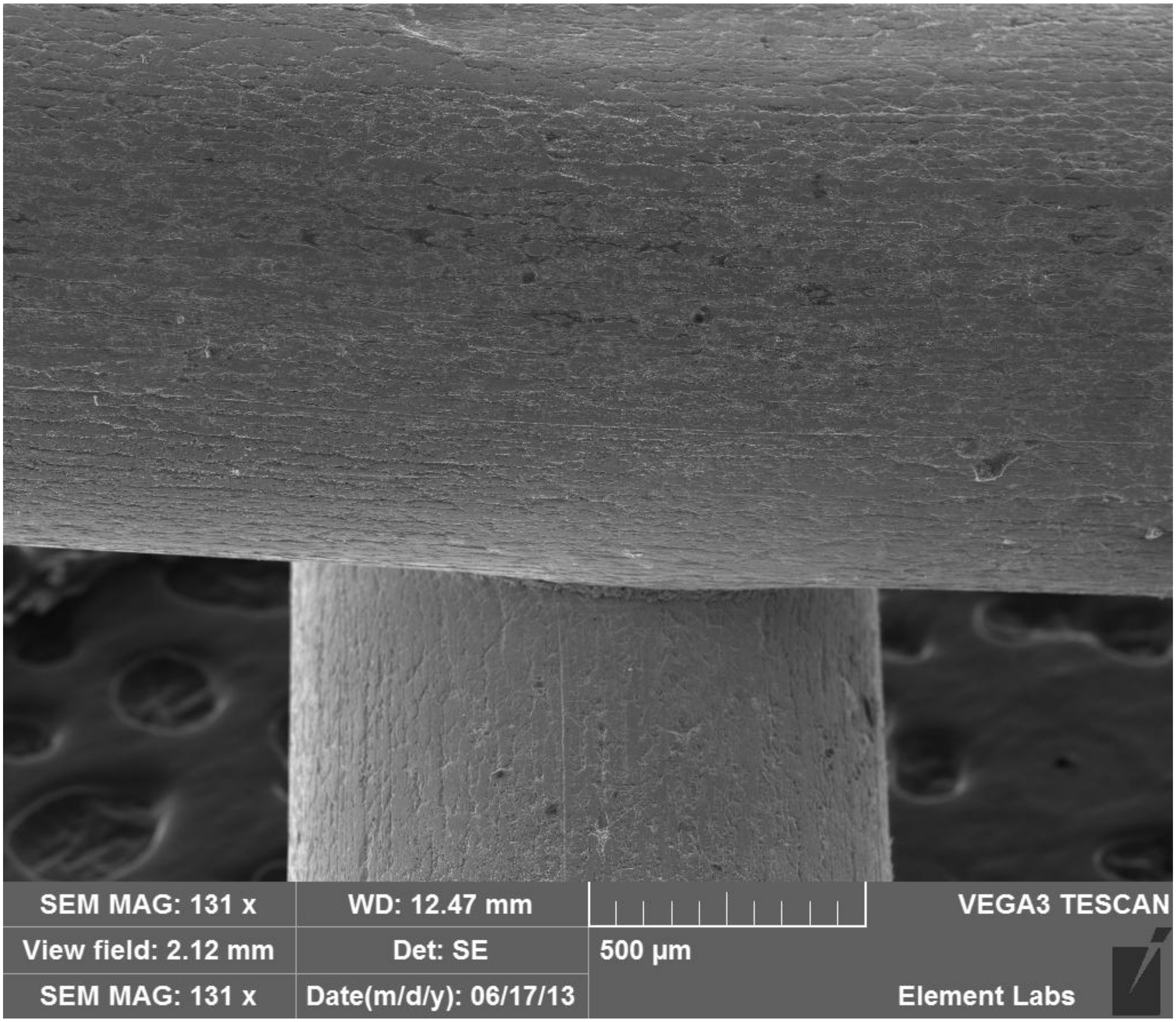
SEM image showing a tilted, view of Sample #4 (Type 316L) from the previous figures. No obvious pits were observed on any of the wire surfaces examined.



SEM image showing a low magnification view of Sample #11 (Type 317L) after 1000 hours of salt spray testing.



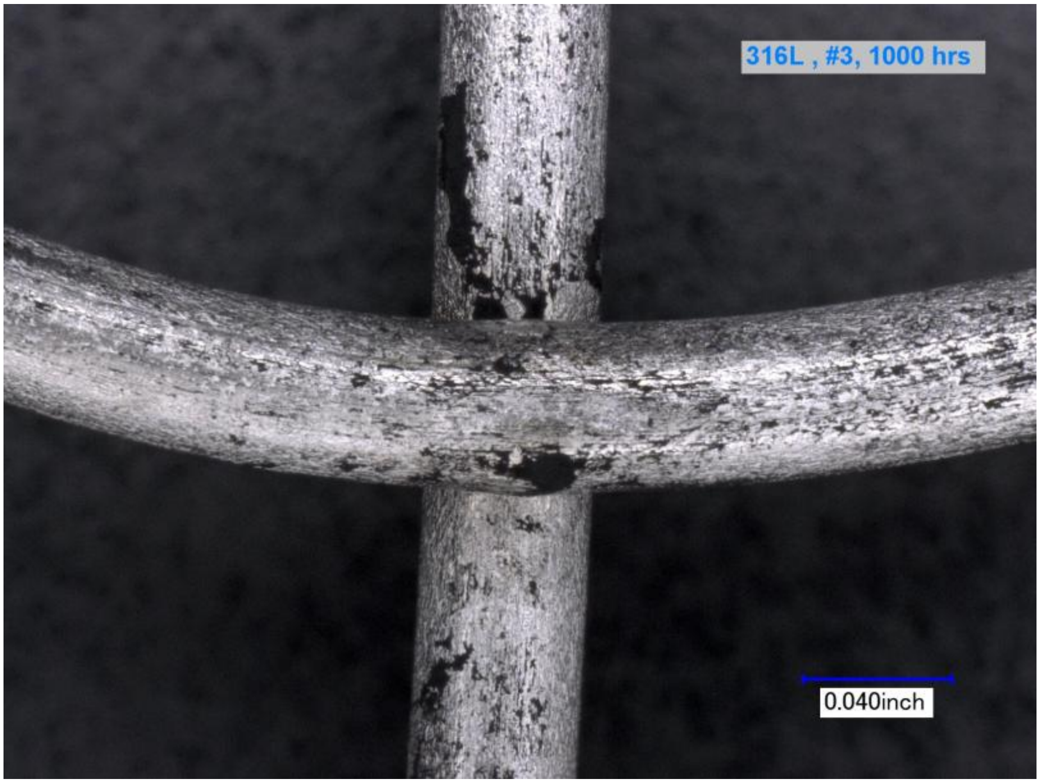
SEM image showing a tilted, low magnification view of Sample #11 (Type 317L) after 1000 hours of salt spray testing. The wire surfaces show evidence of residual carbon black and or salt deposits however no distinct or obvious evidence of pitting damage is visible.



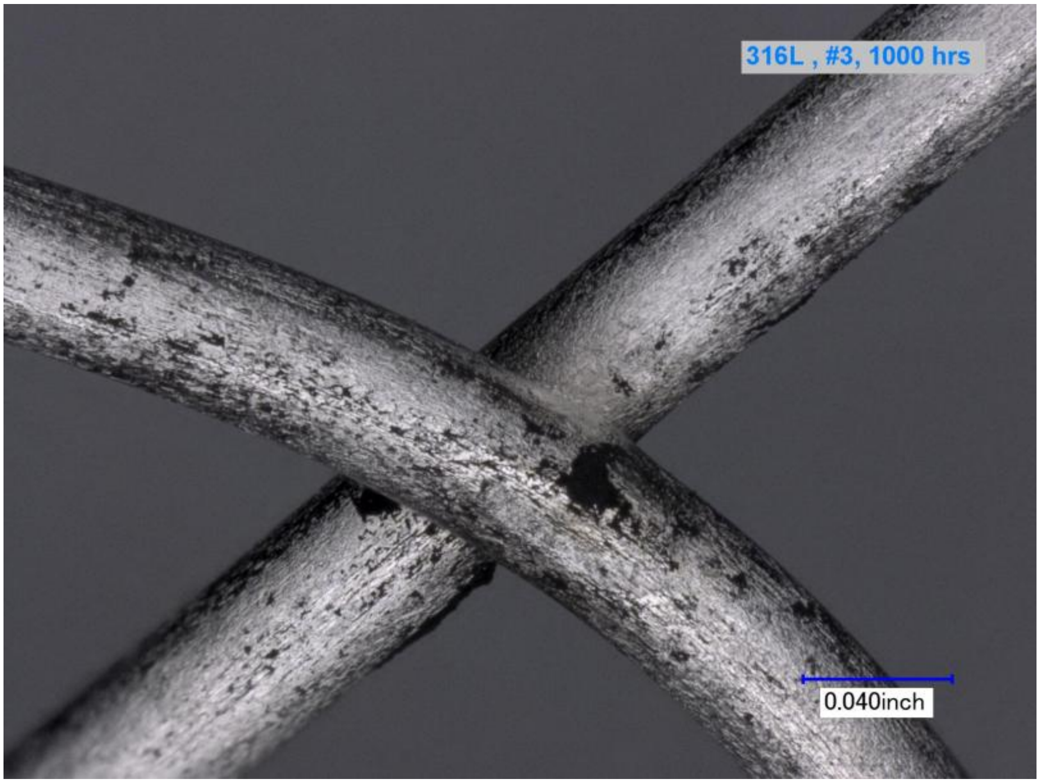
Slightly higher magnification SEM image showing a tilted view of the weld joint from Sample #11 (Type 317L) after 1000 hours of salt spray testing. No evidence of pitting attack was observed on any of the wire surfaces examined.

Compendium of the Solid Wire Sample Images After 1000 Hour Environmental Exposure

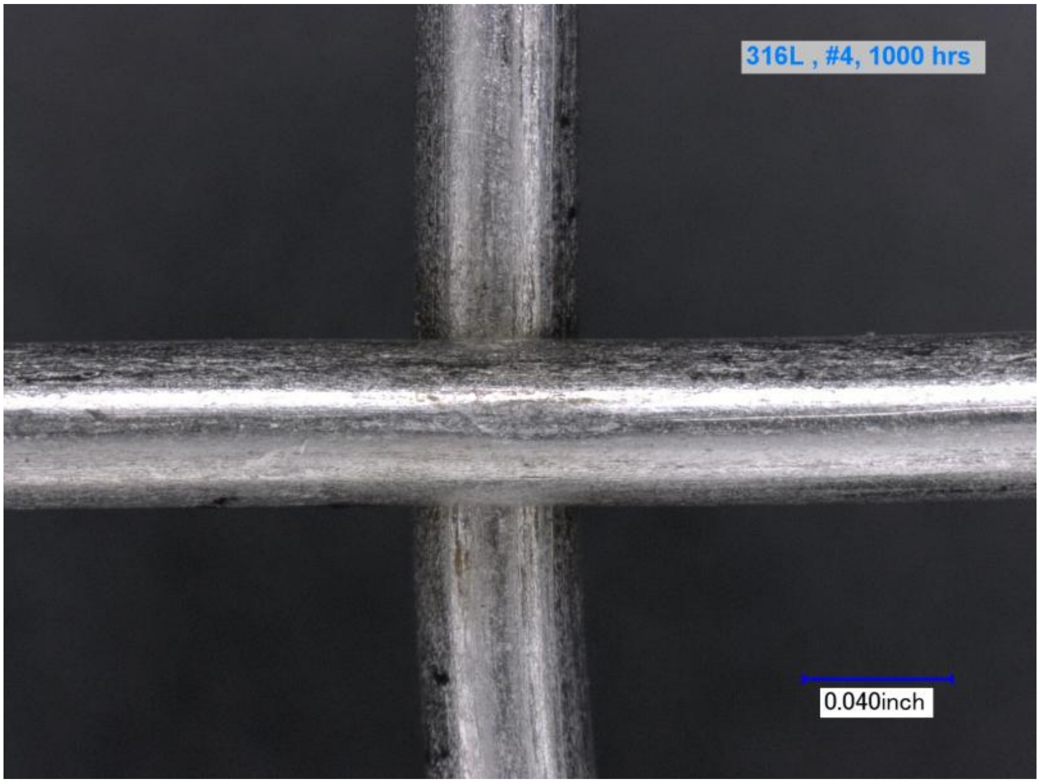
The images presented on page 35, page 36, page 37 and page 38 show different views of the Type 316L solid wire weld samples taken after corrosion testing. Evidence of lamp black can be seen in several of the images (black splotches or patches). None of the samples show obvious or discernable evidence of pitting attack. Slight indications of heat tints can be seen in several of the images.



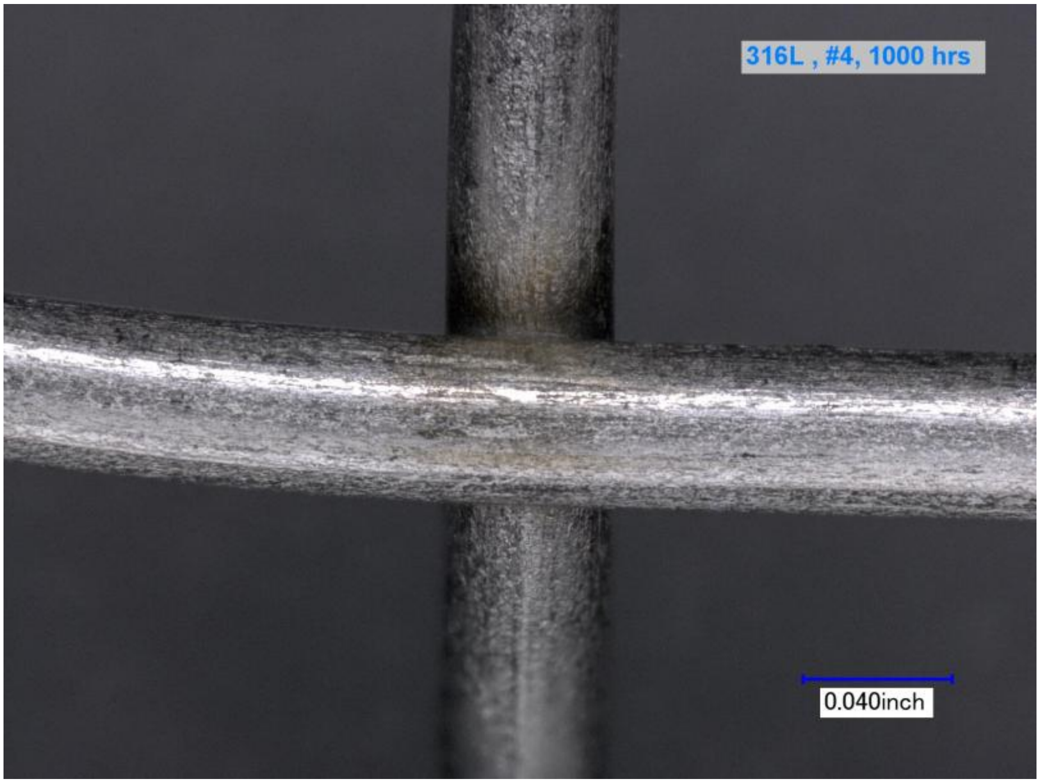
Sample #3-1000hrs-1.jpg



Sample #3-1000hrs-2.jpg

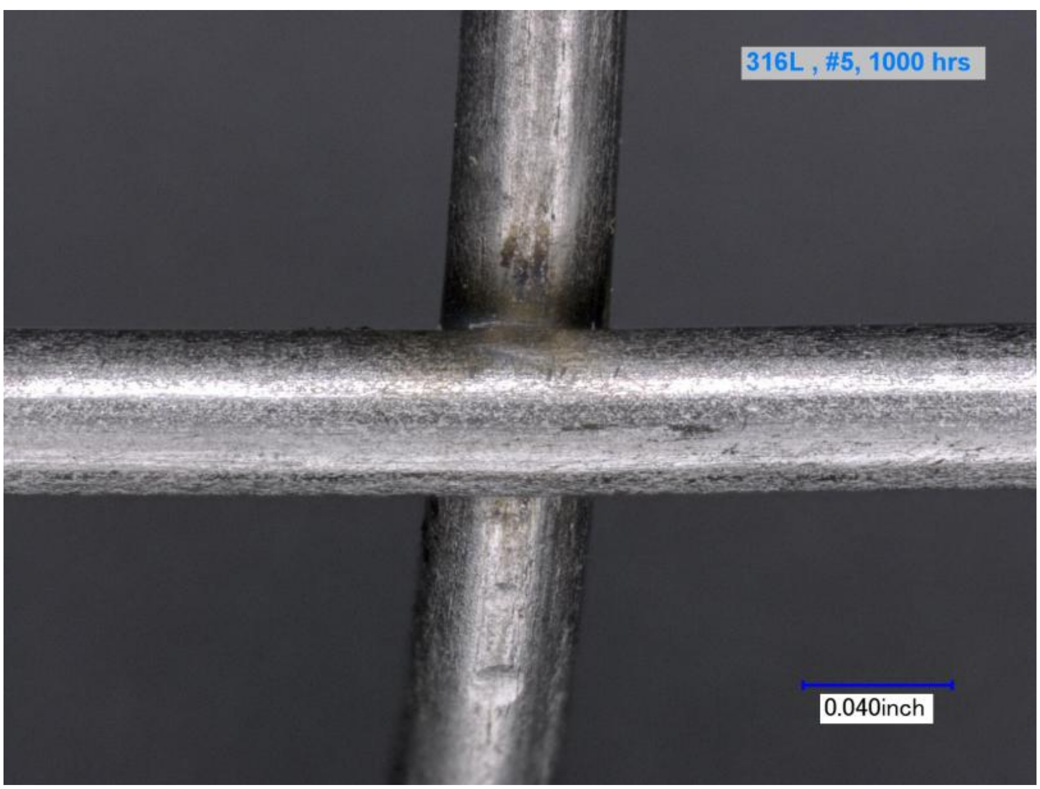


Sample #4-1000hrs-1.jpg

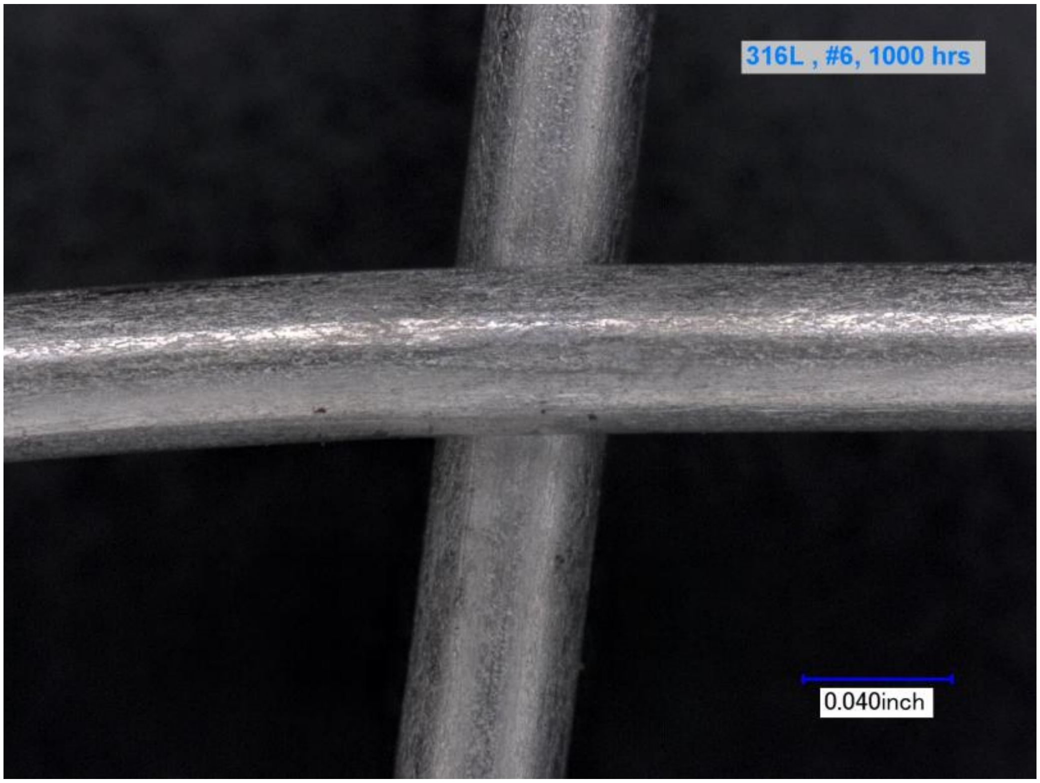


Sample #4-1000hrs-2.jpg

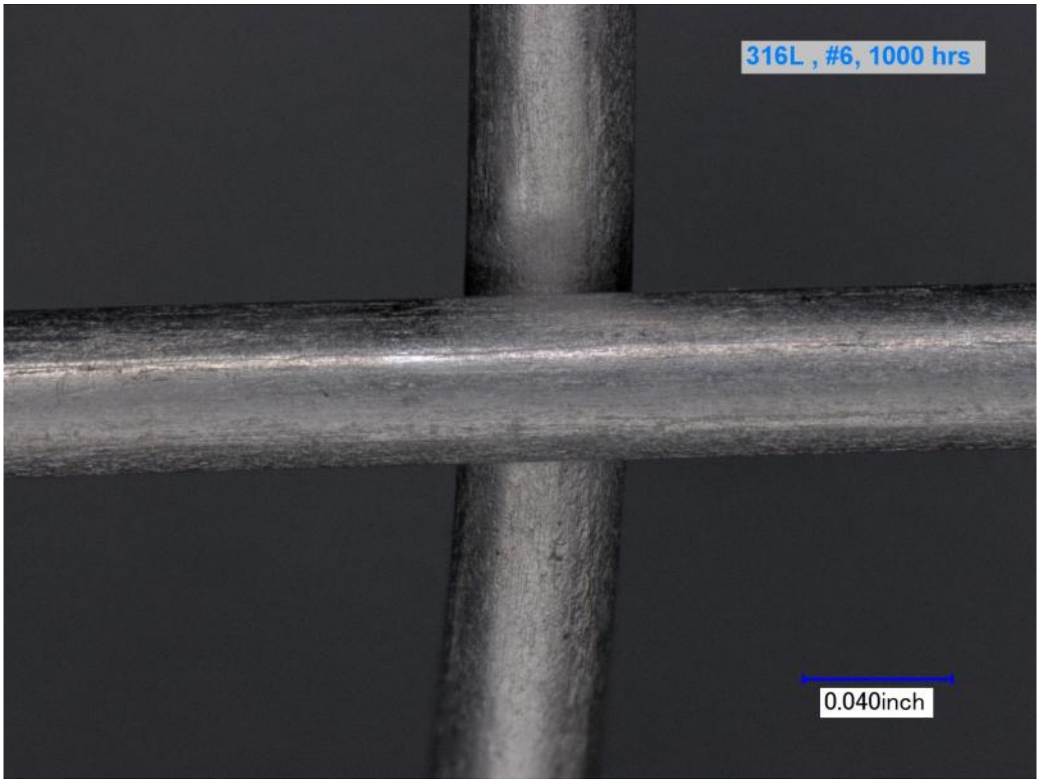
Sample #5-1000hrs-1.jpg



Sample #5-1000hrs-2.jpg



Sample #6-1000hrs-1.jpg

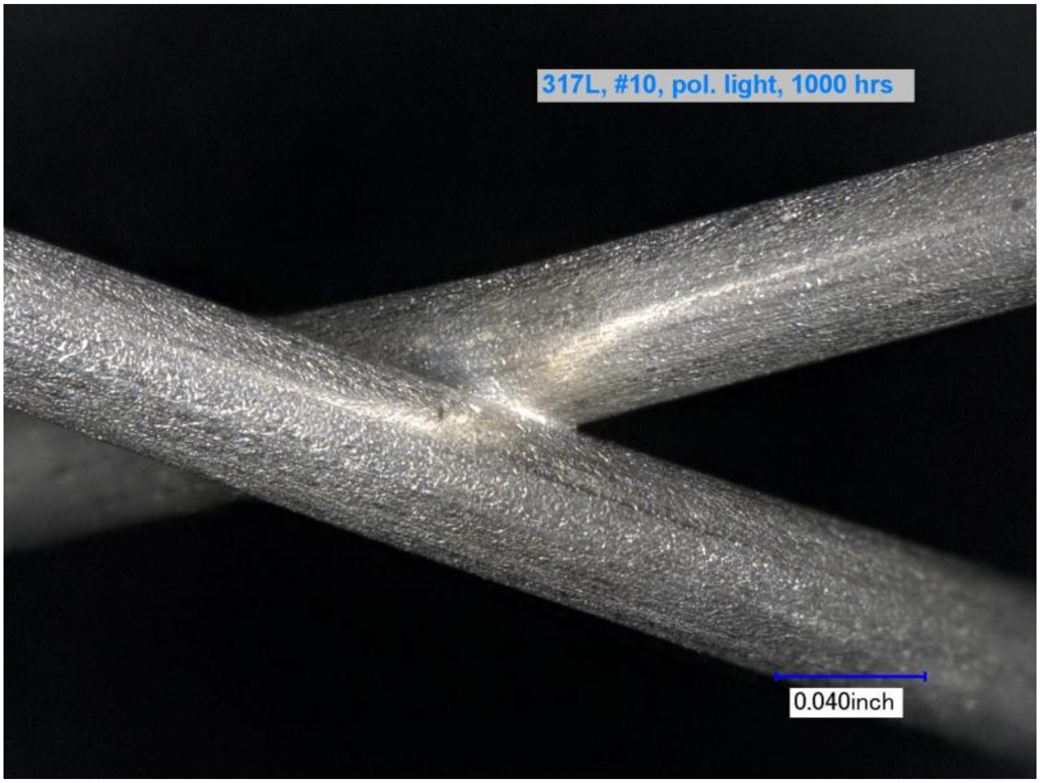


Sample #6-1000hrs-2.jpg

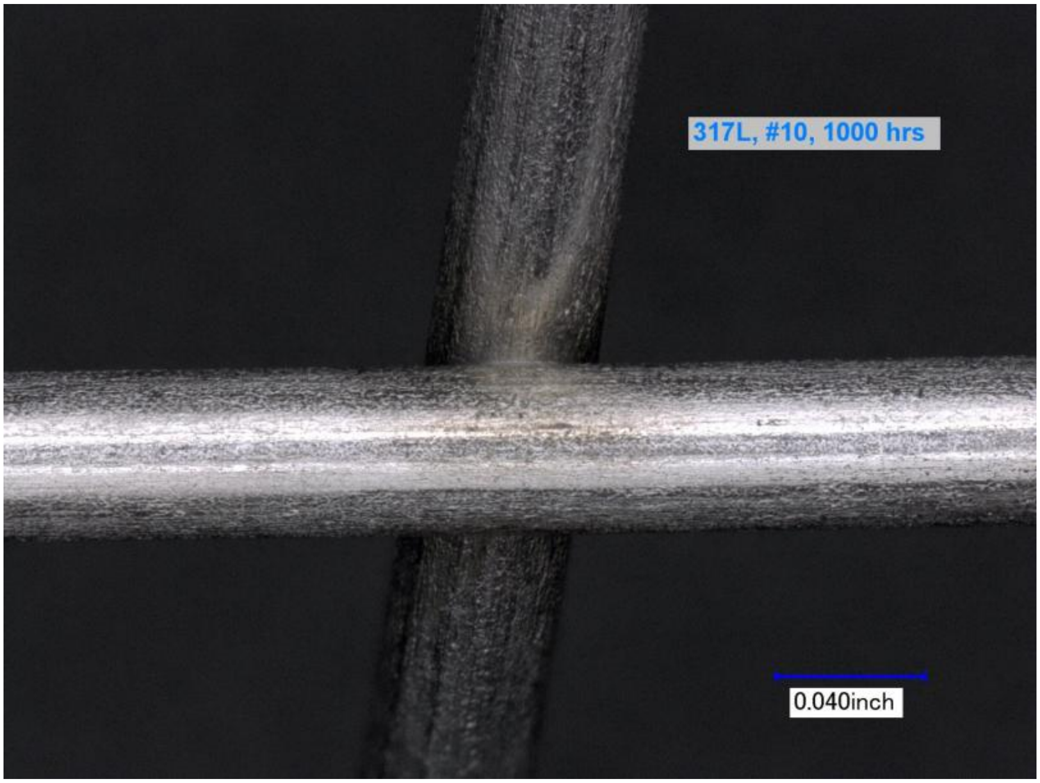
Type 317L Solid Wire Samples After Environmental Exposure

The images presented on pages 40 through 47 show different views of the Type 317L solid wire weld samples taken after corrosion testing. Evidence of lamp black can be seen in several of the images (black splotches or patches). None of the Type 317L samples show obvious or discernable evidence of pitting attack. Slight indications of heat tints can be seen in several of the images.

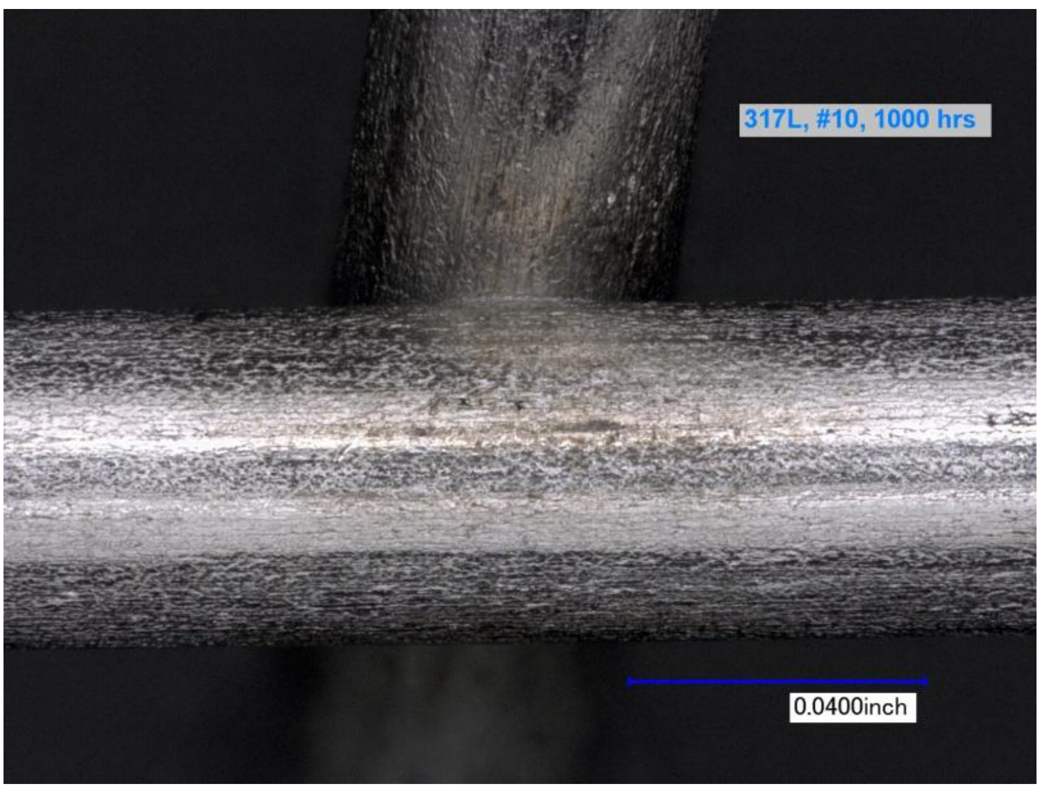
Sample #10-1000hrs-1.jpg



Sample #10-1000hrs-2.jpg

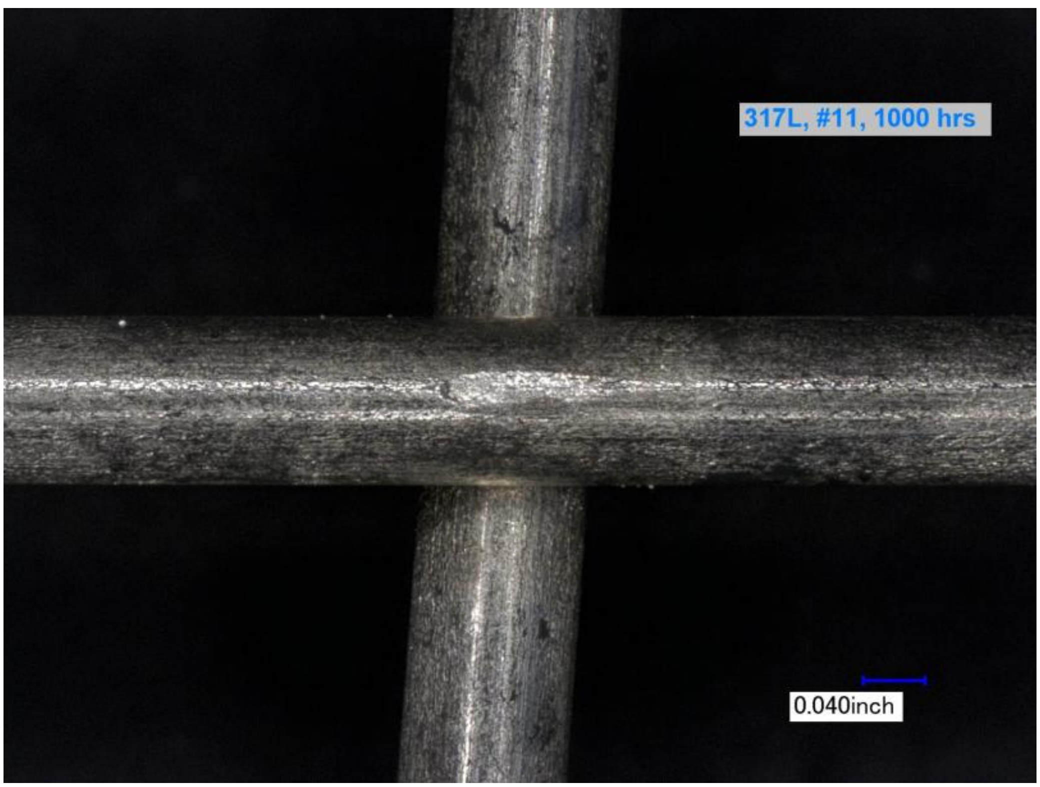


Sample #10-1000hrs-3.jpg

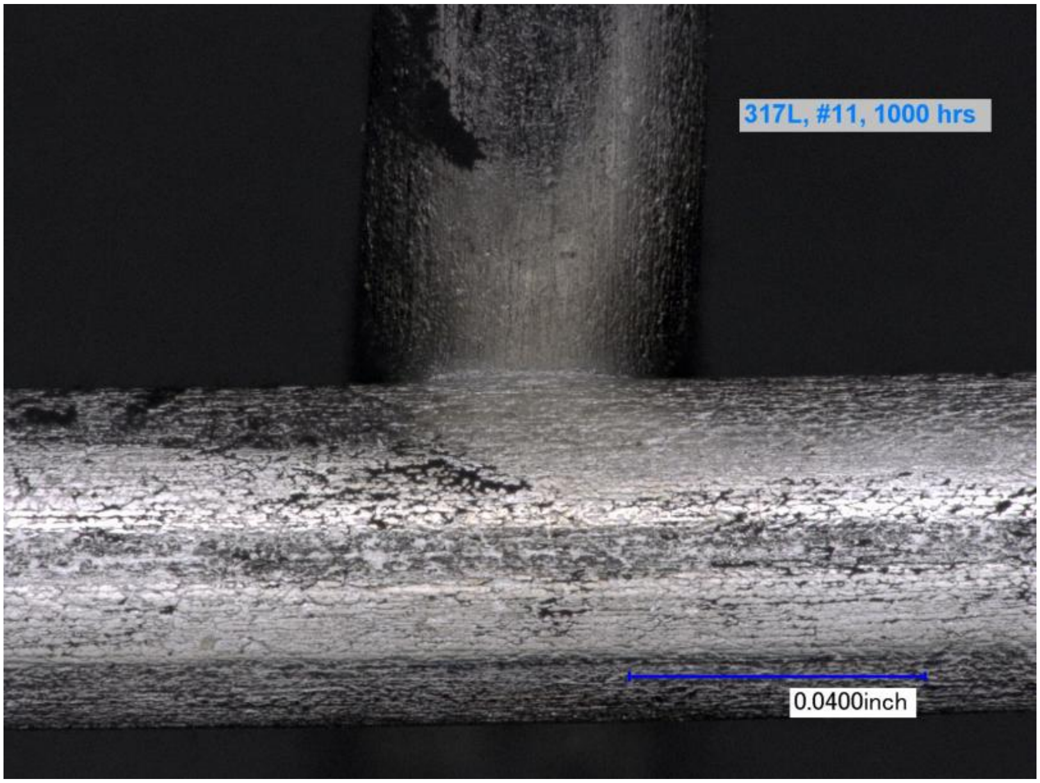


Sample #10-1000hrs-3b.jpg

Sample #10-1000hrs-4.jpg

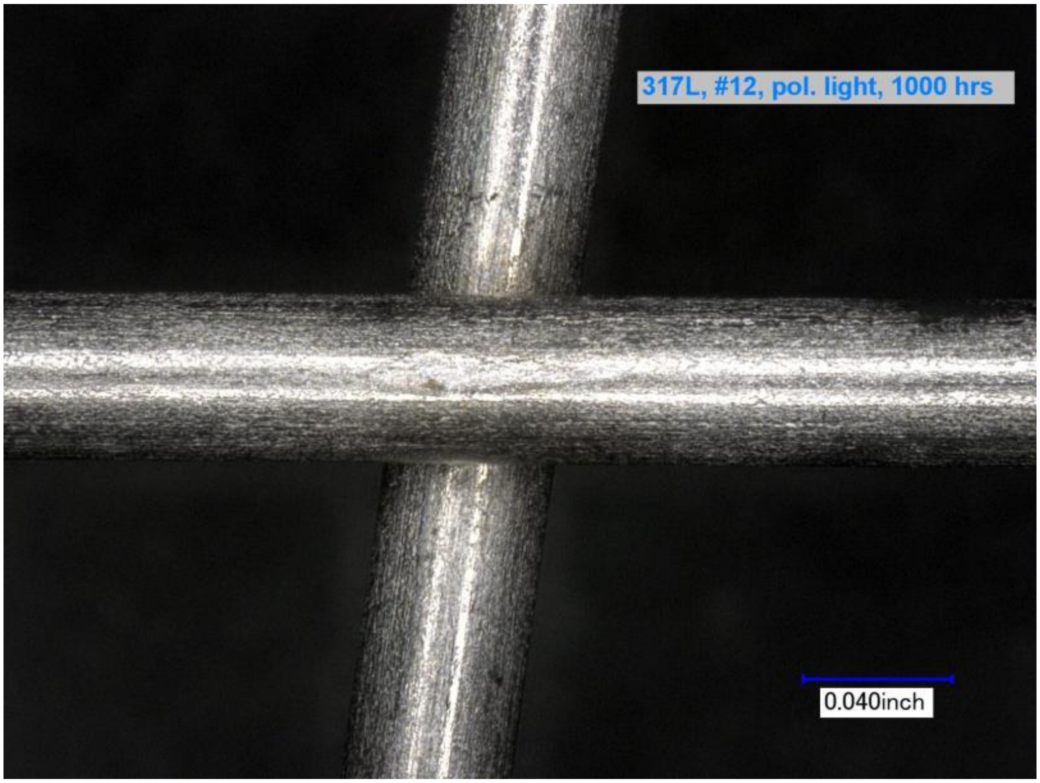


Sample #11-1000hrs-1.jpg

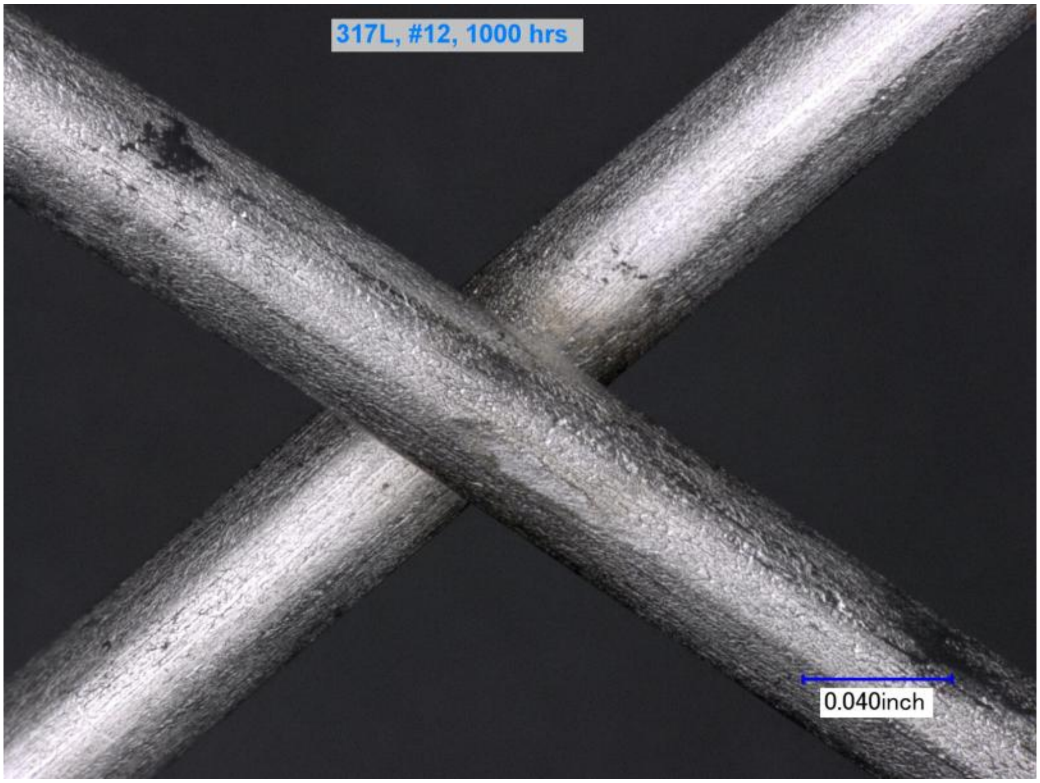


Sample #11-1000hrs-2.jpg

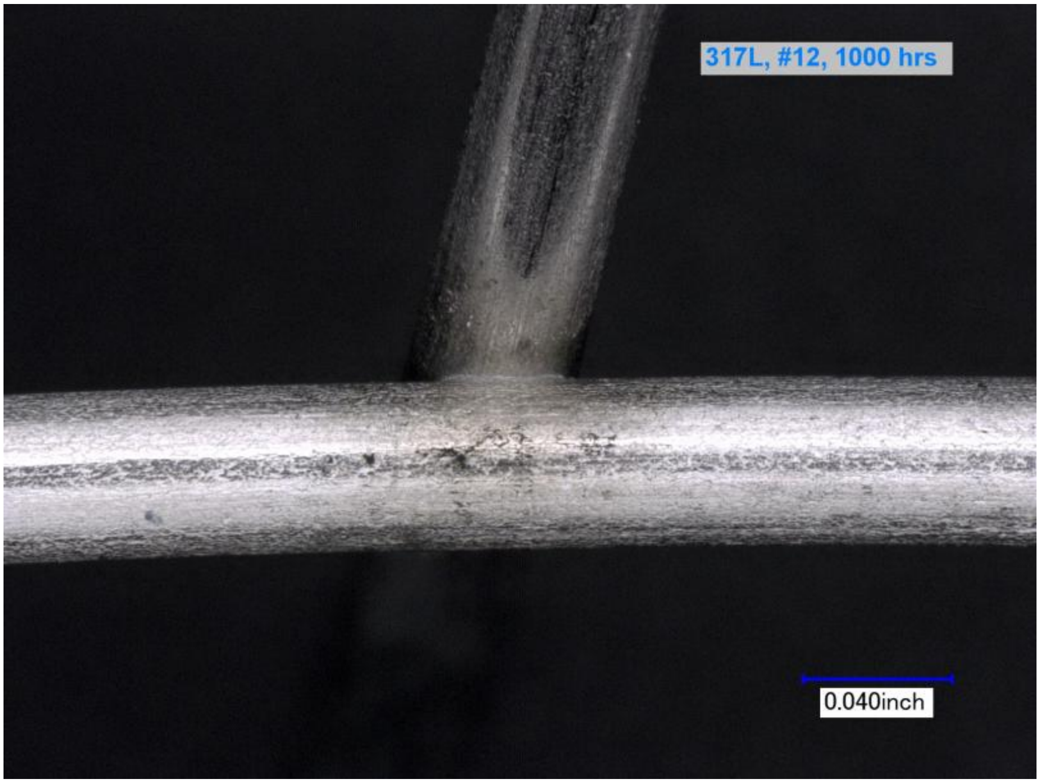
Sample #11-1000hrs-3.jpg



Sample #12-1000hrs-1.jpg

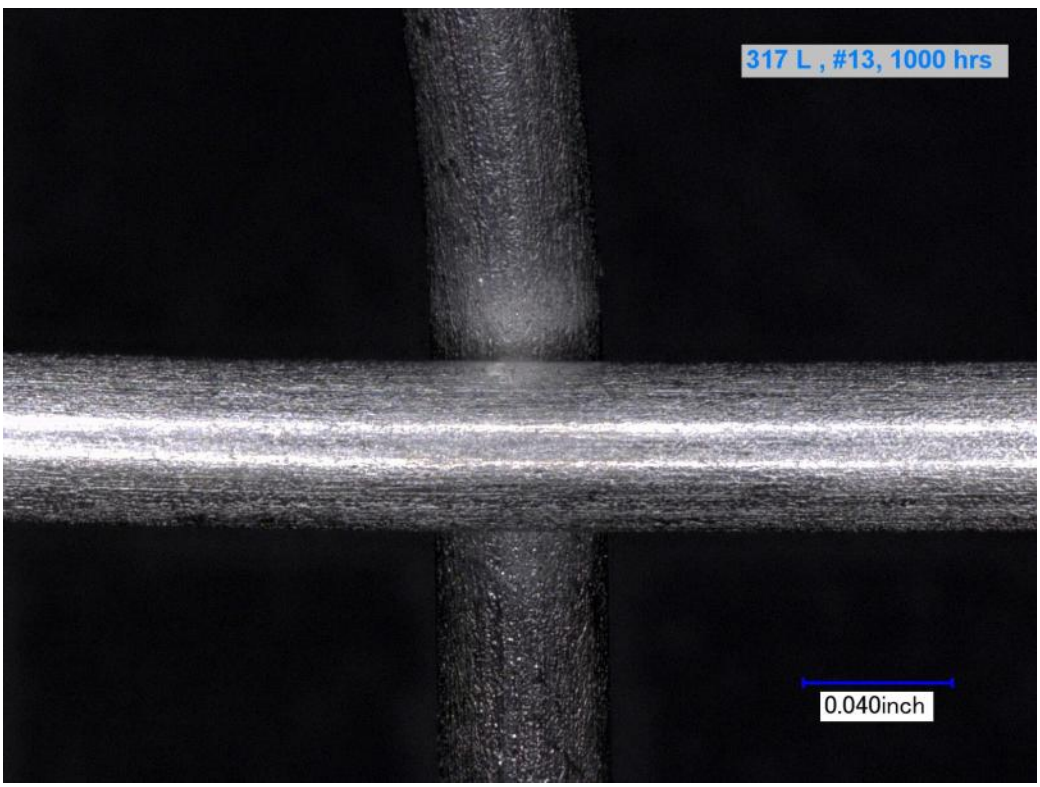


Sample #12-1000hrs-2.jpg

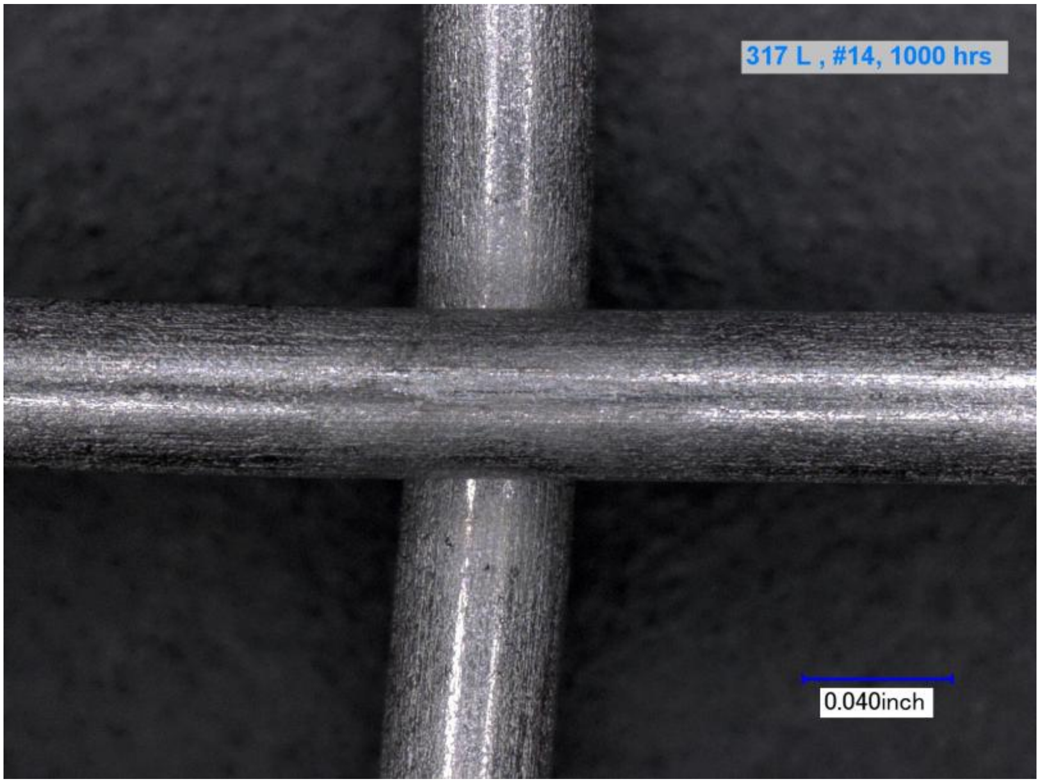


Sample #12-1000hrs-3.jpg

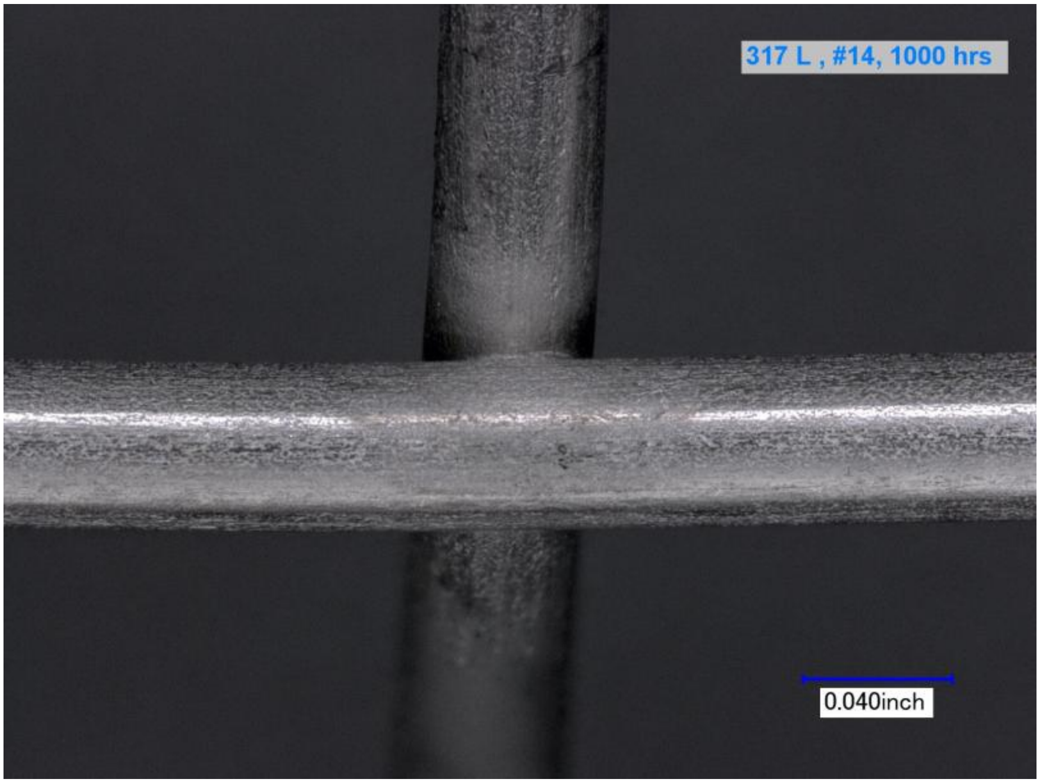
Sample #13-1000hrs-1.jpg



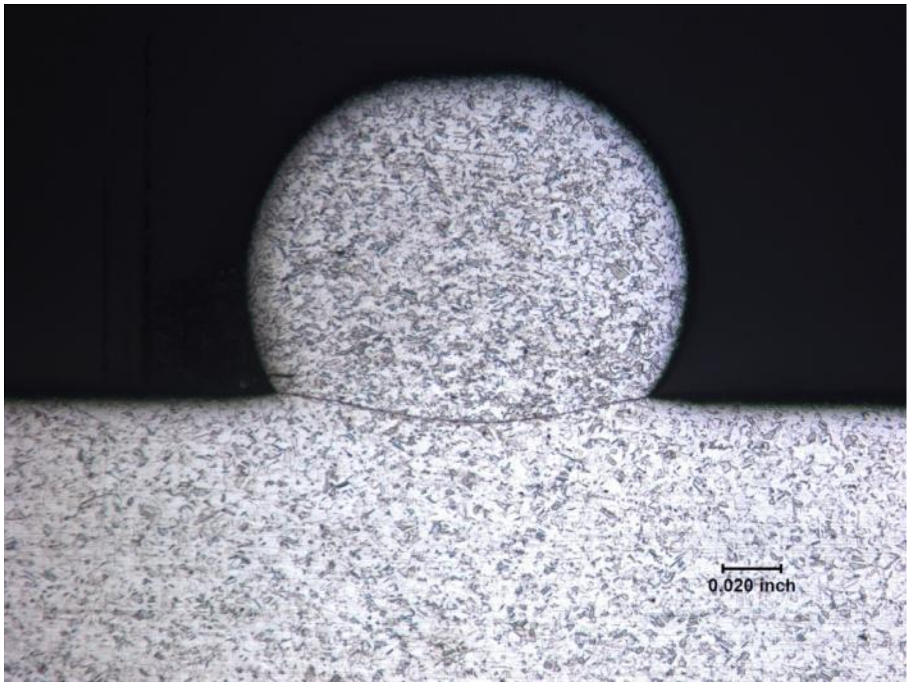
Sample #13-1000hrs-2.jpg

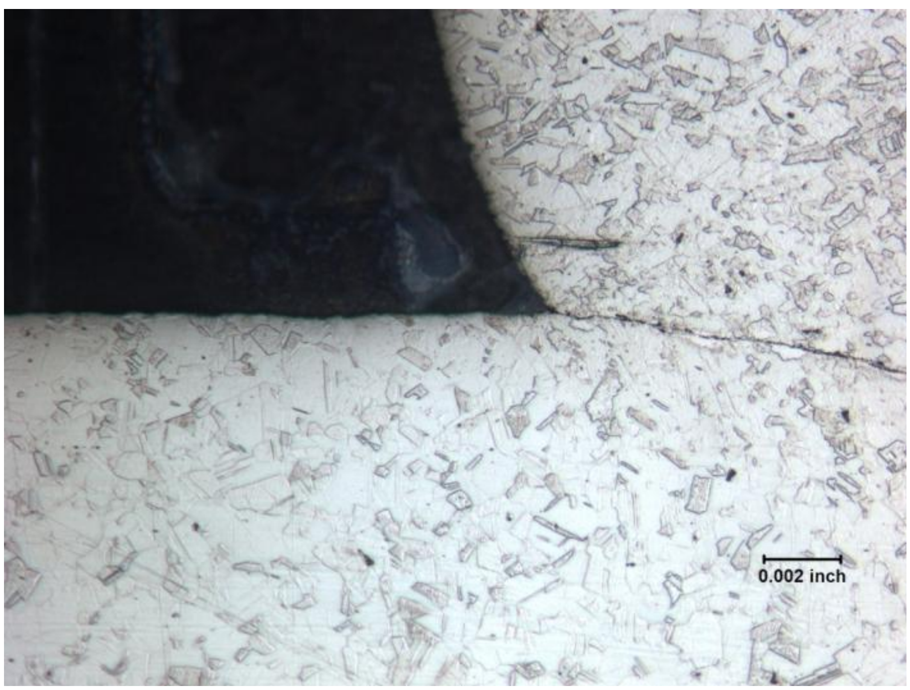


Sample #14-1000hrs-1.jpg

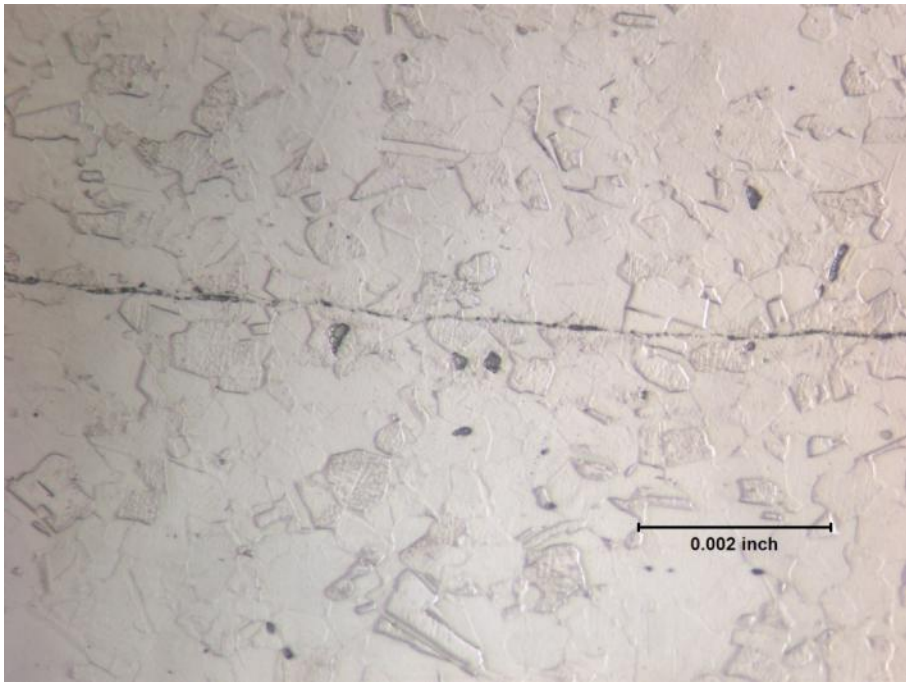


Sample #14-1000hrs-2.jpg

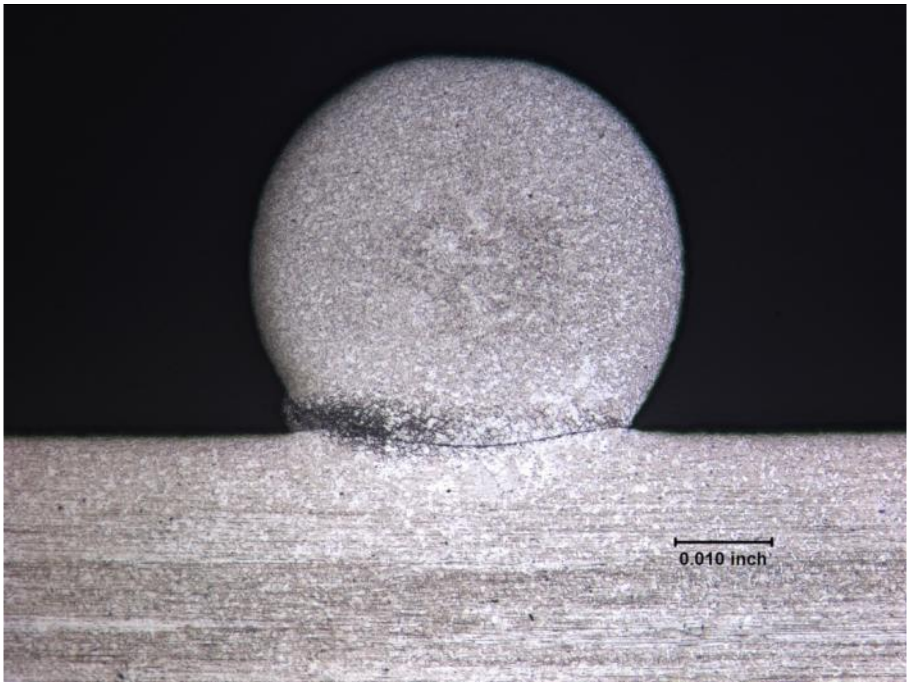


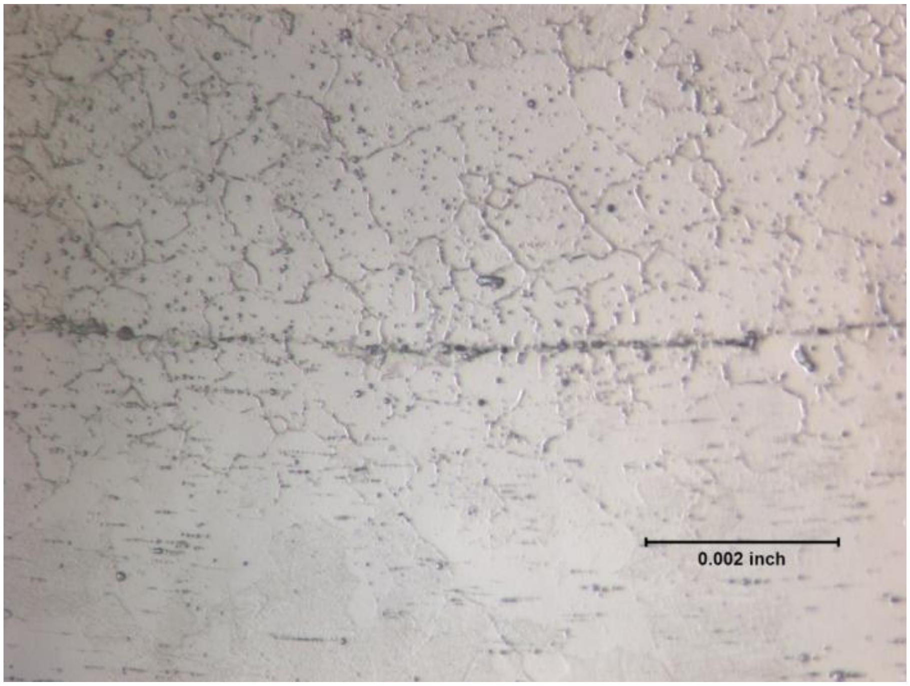


Optical micrographs (50X, 200X) showing the cross section from Sample #3 (Type 316L) after electrolytic Oxalic acid etching as specified in ASTM Specification A262, Practice A for rapid screening of sensitization. The etched microstructure showed no significant evidence of ditched grain boundaries indicating that sample was not sensitized.

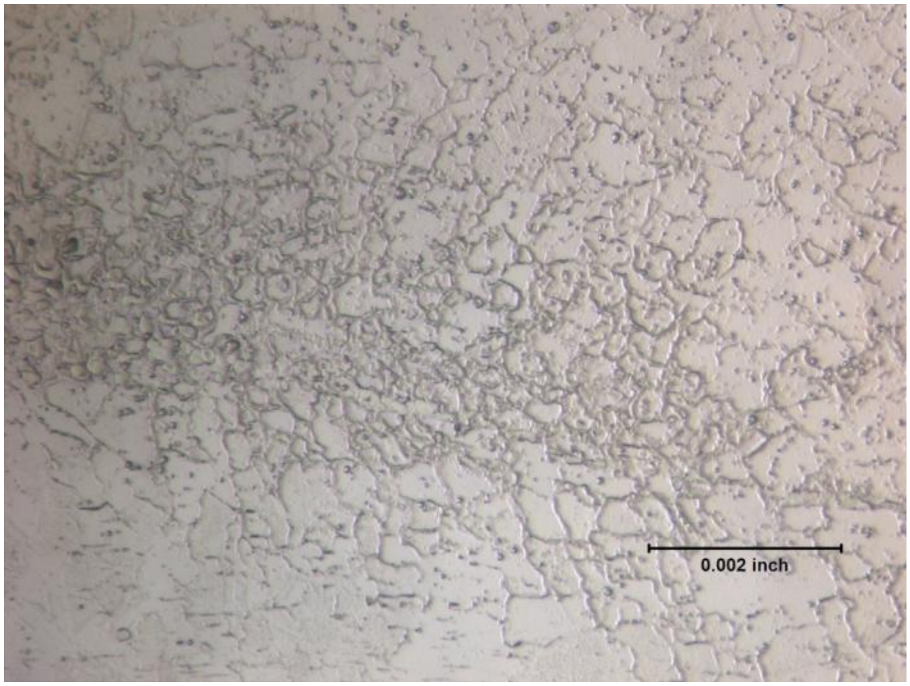


Optical micrograph (500X) showing a higher magnification view of the bond line from the Sample #3 (Type 316L) weld cross section shown in the previous image. No significant evidence of grain boundary ditching is visible which is the feature observed when a material is sensitized and has been etching using the Oxalic acid procedure detailed in ASTM Specification A262, Practice A.





Optical micrographs (50X, 500X) showing the cross section from Sample #10 (Type 317L) after electrolytic Oxalic acid etching as specified in ASTM Specification A262, Practice A for rapid screening of sensitization. The etched microstructure showed no significant evidence of ditched grain boundaries indicating that sample was not sensitized.



Optical micrograph (500X) showing a higher magnification view of the bond line from the Sample #10 (Type 317L) weld cross section shown in the previous image.   No significant evidence of grain boundary ditching is visible which is the feature observed when a material is sensitized and has been etching using the Oxalic acid procedure detailed in ASTM Specification A262, Practice A.

ANACHEM LABORATORIES

TEST REPORT

Established 1948

140 Standard Street · El Segundo, California 90245.3832 · voice 310.322.4993 · fax 310.322.6681

TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE May 29, 2013
LAB NO. B73976 pg.1 of 3
CUST P.O.
SAMPLE NO. 62107
RECEIVED 4/8/13

SAMPLE: 5 pcs 316L Annealed 0.044" Solid Wire Welded Cross

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received
CONDITION: None - test as received
TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
3	No visible change
4	No visible change
5	No visible change
6	No visible change
7	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

ANACHEM LABORATORIES

TEST REPORT

Established 1948

140 Standard Street • El Segundo, California 90245.3832 • voice 310.322.4993 • fax 310.322.6681

TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE	May 29, 2013
LAB NO.	B73976 pg.2 of 3
CUST P.O.	
SAMPLE NO.	62107
RECEIVED	4/8/13

SAMPLE: 5 pcs 317L Annealed 0.044" Solid Wire Welded Cross

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received
CONDITION: None - test as received
TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
10	No visible change
11	No visible change
12	No visible change
13	No visible change
14	No visible change

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

ANACHEM LABORATORIES

TEST REPORT

Established 1948

140 Standard Street • El Segundo, California 90245.3832 • voice 310.322.4993 • fax 310.322.6681

TOMAS OSINSKI DESIGN INC.
4240 Glenmuir Avenue
Los Angeles, CA 90065

ATTN: Tomas Osinski

DATE	May 29, 2013
LAB NO.	B73976 pg.3 of 3
CUST P.O.	
SAMPLE NO.	62107
RECEIVED	4/8/13

SAMPLE: 5 pcs 321 Annealed 0.044" Solid Wire Welded Cross

SO2 SALT SPRAY PER ASTM G85-11 Annex A4, Cycle A4.4.4.1

PRECLEAN: None - test as received
CONDITION: None - test as received
TESTING: Coat samples with Lamp Black
Rack samples and apply approximate 2-lb weight
1000 hours @ 95±3°F
Constant spray of 5±1 %/wt Sodium Chloride
Injection of SO_2 gas at a rate of 1 ml/min/ft^3 of chamber space for one hour every six hours to maintain a pH of 2.5-3.2
POSTCLEAN: Rinse in running DI water not warmer than 100°F immediately upon removal from chamber and air dry
EVALUATION: Final evaluation by customer

SAMPLE	OBSERVATION
17	Red rust @ 68 hours - broke and discontinued @ 354 hours
18	Red rust @ 68 hours - broke and discontinued @ 596 hours
19	Red rust @ 68 hours - broke and discontinued @ 260 hours
20	Red rust @ 68 hours - broke and discontinued @ 744 hours
21	Red rust @ 68 hours - broke and discontinued @ 500 hours

SAMPLES RETURNED TO CUSTOMER FOR EVALUATION

C. Matthews
General Manager

Accredited Nadcap Materials Testing Laboratory

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7.4 PRE-ENVIRONMENTAL CORROSION TEST IMAGES-SOLID WIRE

Included in this section:

- Element Materials Technology Report #TOM002-21955C Final Titled *“Before” Images of Solid Wire Weld Samples (Sunstone 2500 Equipment) Made From Type 316L, Type 317L and Type 321 Stainless Steel*

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Los Angeles, CA, 90065

Date: July 2, 2013
Author: Hugo A. Menendez

ELEMENT Report #: TOM002-21955C Final

"Before" Images of the Solid Wire Weld Samples (SUNSTONE 2500 Equipment) Made From Type 316L, Type 317L and Type 321 Stainless Steel

Prepared by:

Hugo A. Menendez
Department Manager, Failure Analysis, Metallurgist
Element Materials Technology – Huntington Beach

INTRODUCTION

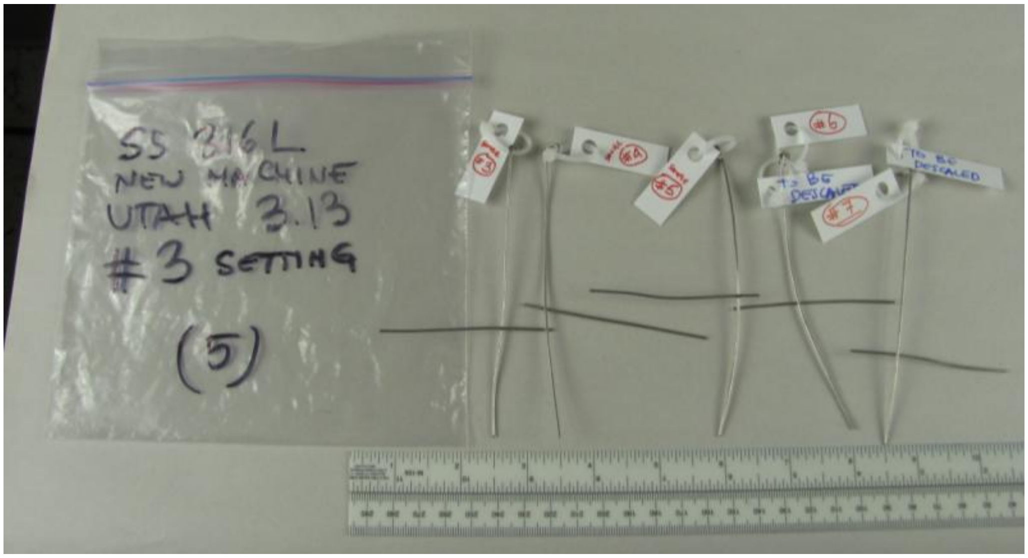
Element personnel were asked to provide metallurgical laboratory and consulting services regarding the candidate stainless steels being considered for the Eisenhower Memorial Tapestry project. All samples provided and reviewed are listed in the Alloy Sample Matrix dated July 8th, 2013. Photographs of the solid wire resistance welded samples were taken before and after the 1000 hour environmental exposure, as well as after descale / passivation prior to the salt spray test. The images presented in this report are for record and comparison purposes to the after salt spray images contained in Element Report TOM002-04-04-21955B.

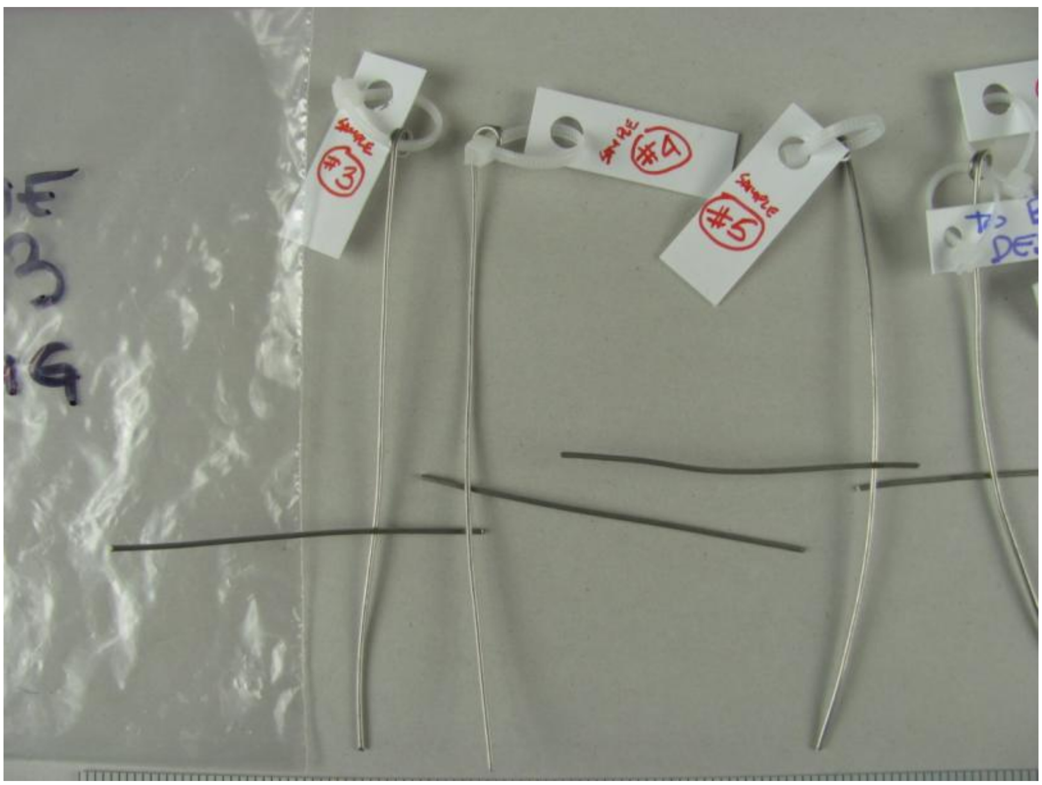
OBJECTIVE

Provide metallurgical support / consulting services relative to evaluating the performance variations, if any, between the three groups of welded wires being evaluated for use in the Eisenhower Memorial Tapestry.

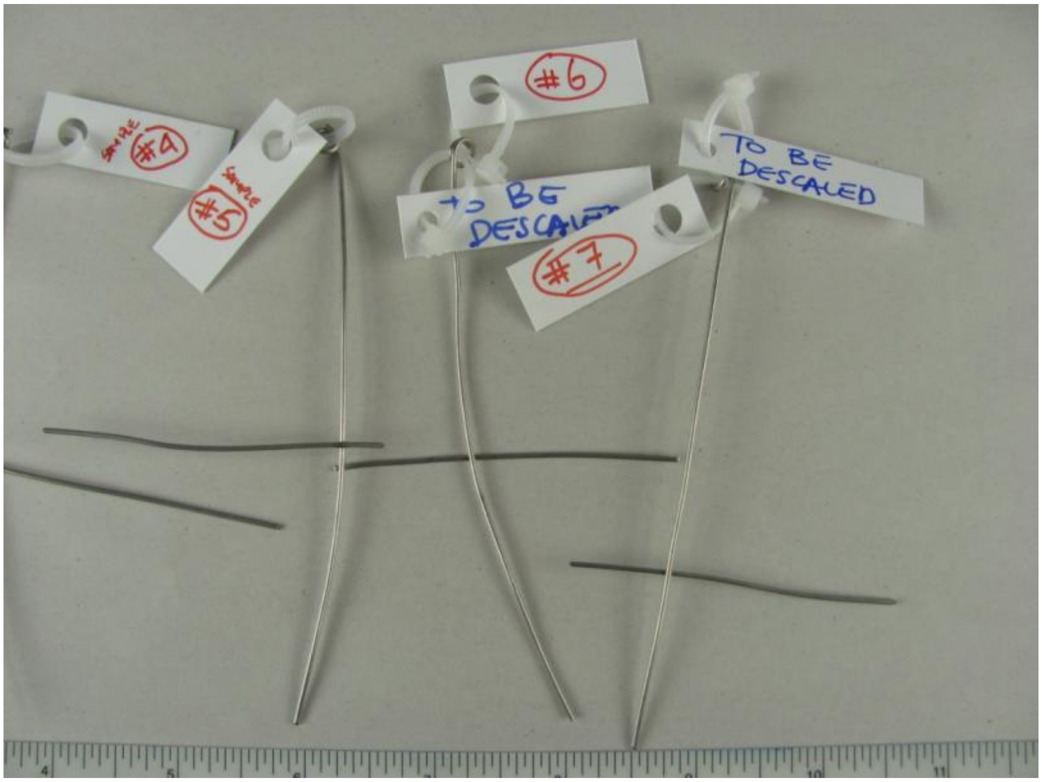
SUMMARY & CONCLUSIONS

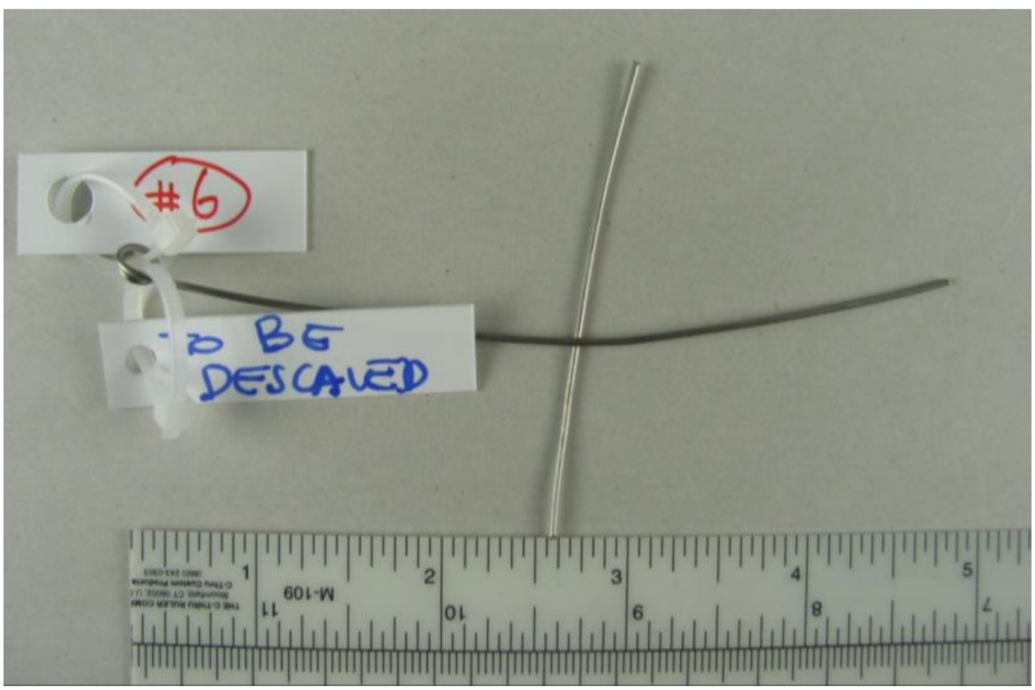
All of the images presented in this report were taken prior to exposing the samples to a 1000 hour salt spray test that was performed at Anachem Laboratories, Inc., in El Segundo. The solid wire welds were made using the Sunstone 2500 equipment. Select samples were descaled and passivated as specified in the testing matrix provided. With the exception of the macro photographs all of the images in the report were taken using a Keyence VX-2000 digital stereo microscope. Evidence of light heat tint can be seen in several of the images.



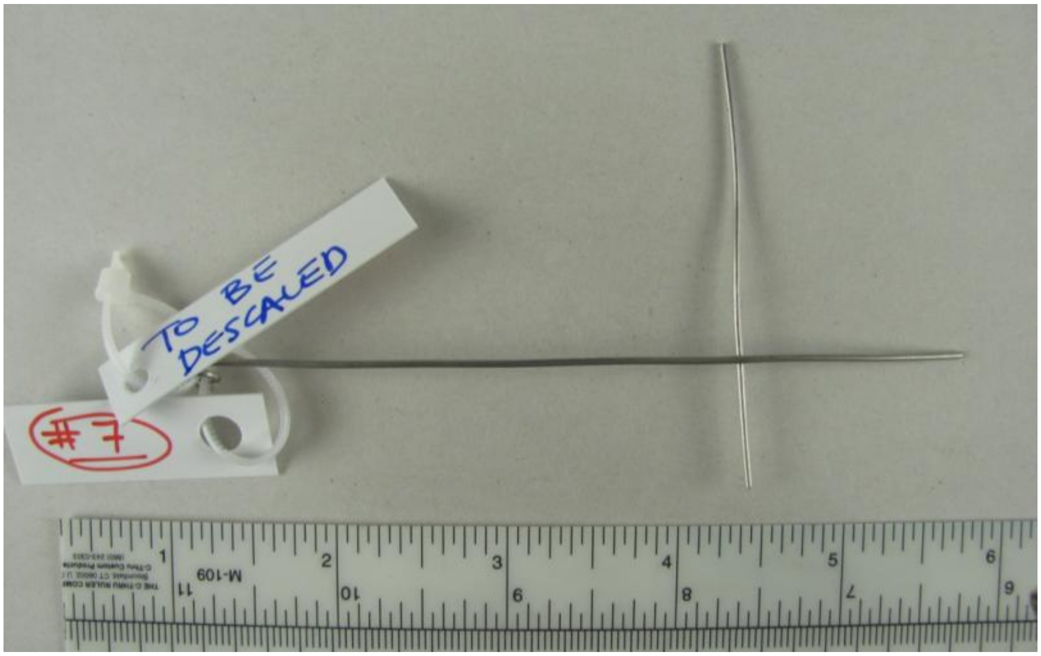


Macro photographs showing the Type 316L solid wire weld samples submitted for evaluation, as-received prior to descale / passivation and salt spray testing. Sample #3, #4, #5, #6 and #7 are shown.

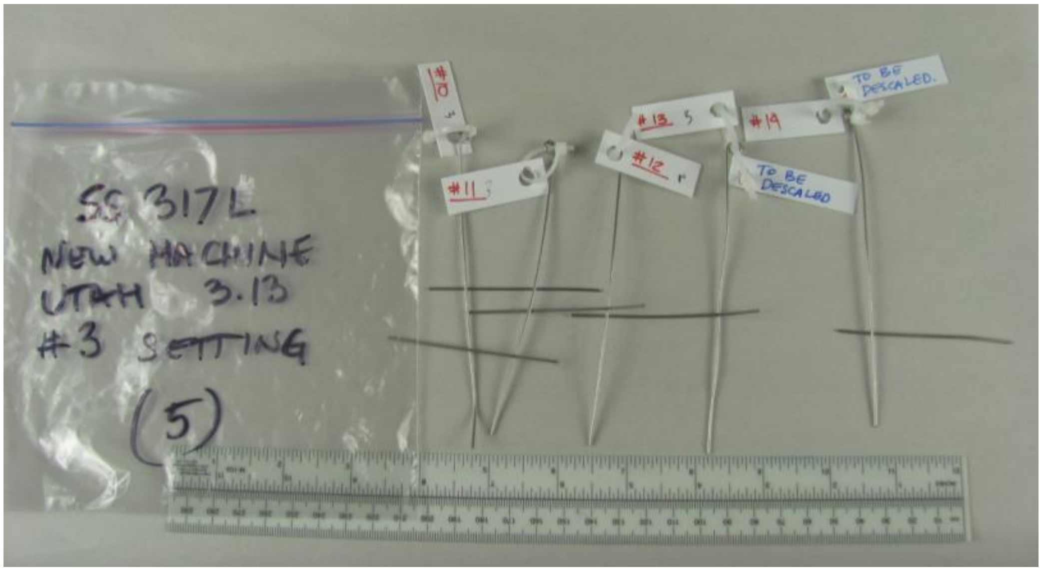




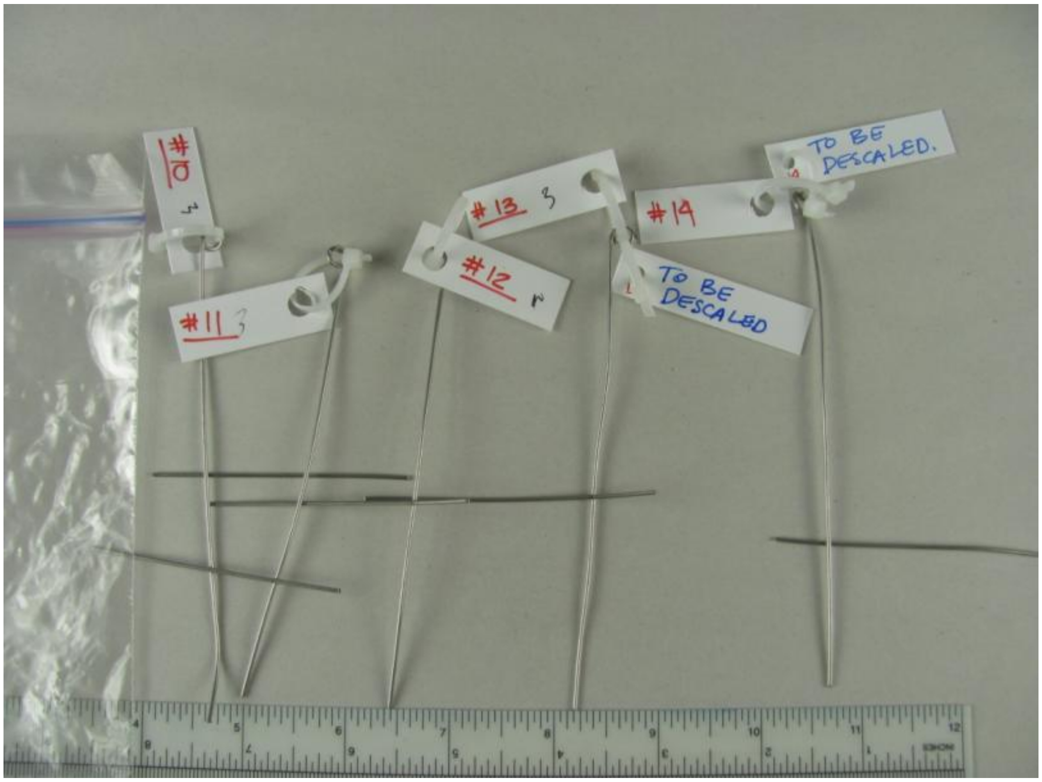
Macro photographs showing some of the Type 316L solid wire weld samples and tags prior to descale / passivation and salt spray testing. Sample #4, #5, #6 and #7 are shown.

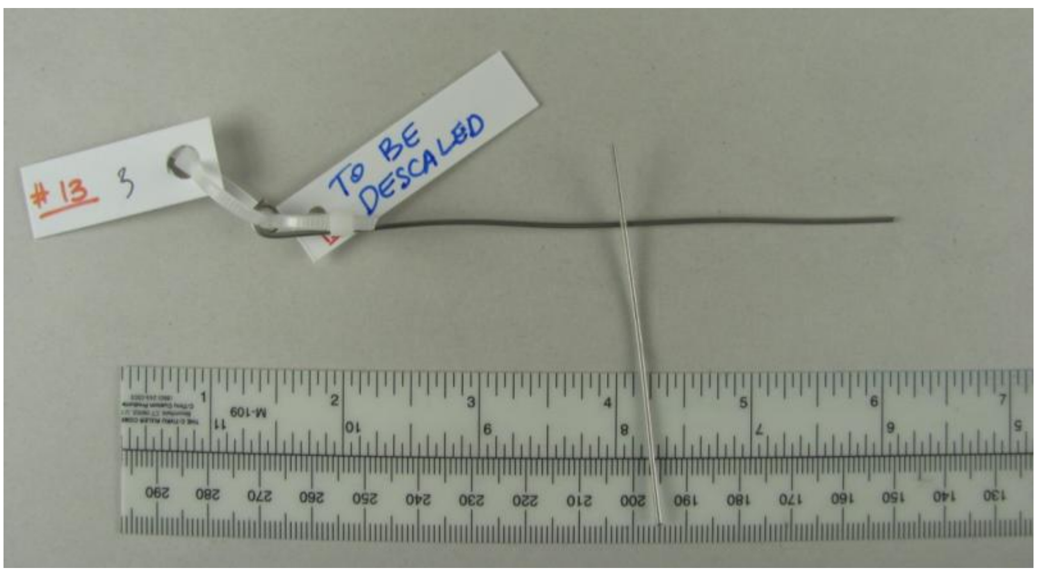


Macro photograph showing one of the Type 316L solid wire weld samples to be descaled / passivated prior to salt spray testing. Sample #7 is shown.

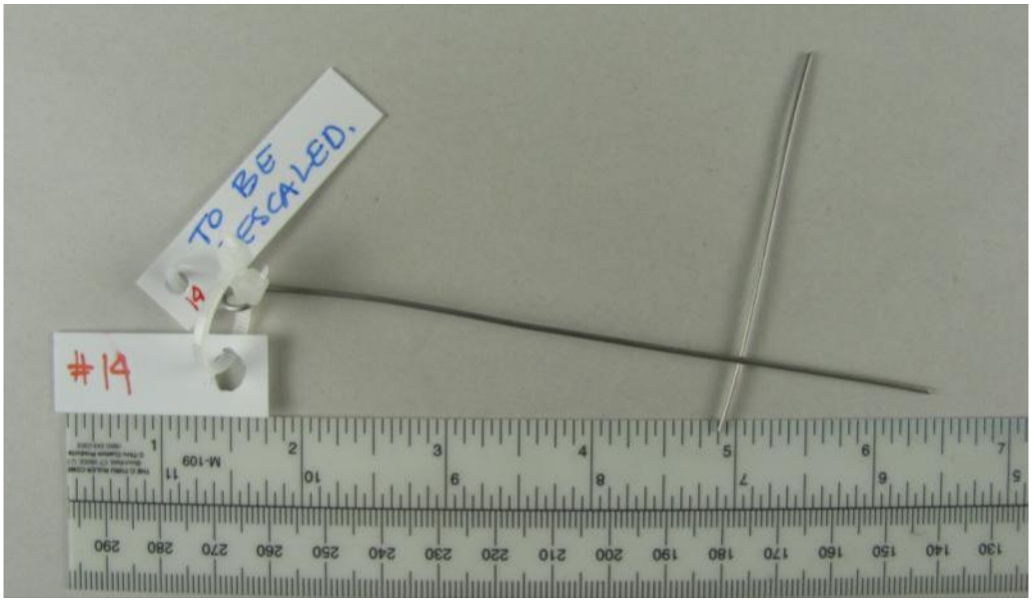


Macro photographs showing the as-received Type 317L solid wire weld samples submitted for evaluation (prior to descale / passivation and salt spray testing). Sample #10, #11, #12, #13 and #14 are shown.

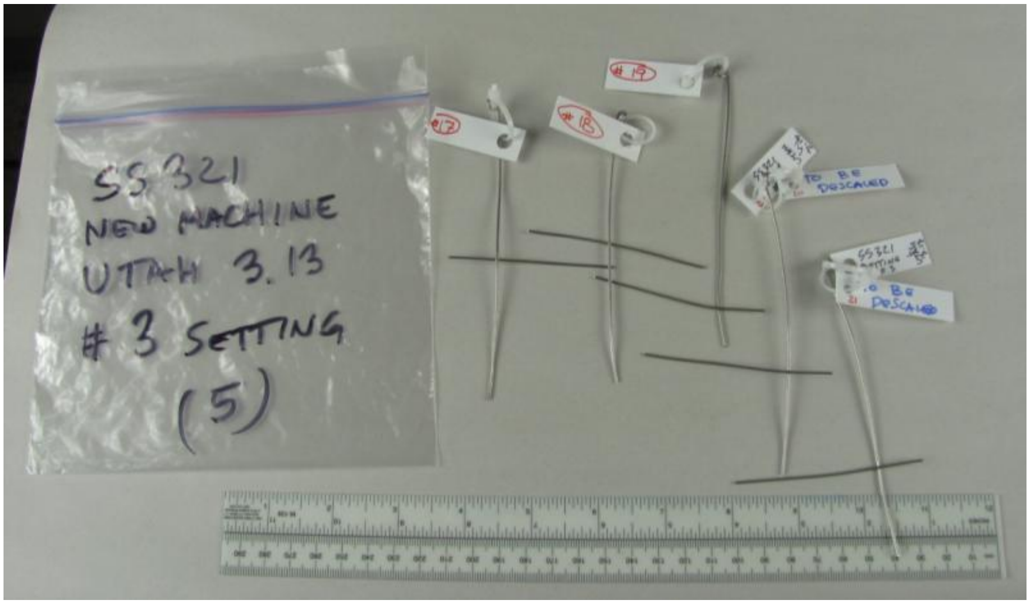




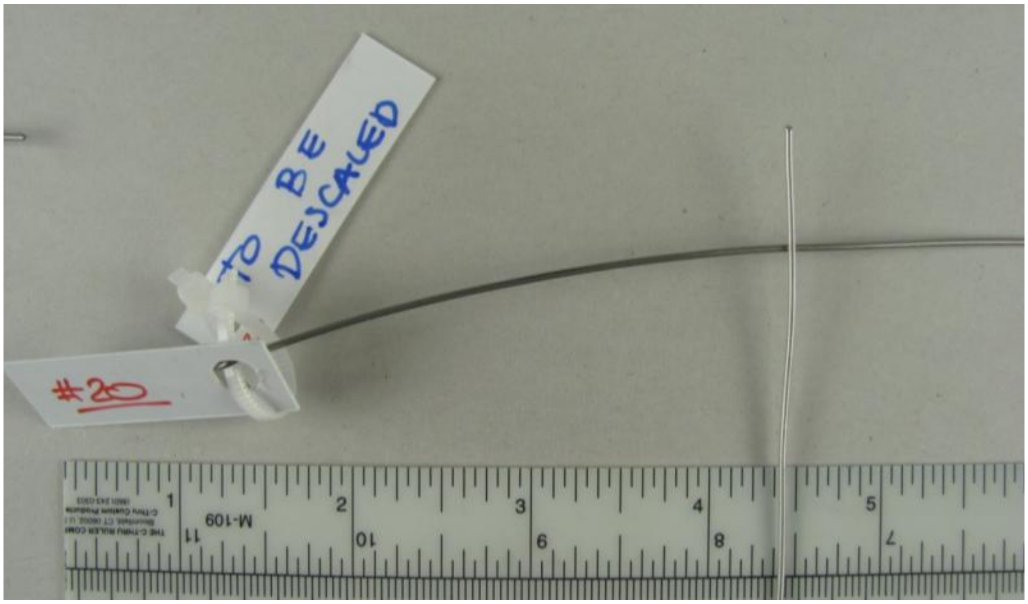
Macro photographs showing some of the as-received Type 317L solid wire weld samples and tags prior to descale / passivation and salt spray testing. Sample #10, #11, #12, #13 and #14 are shown.

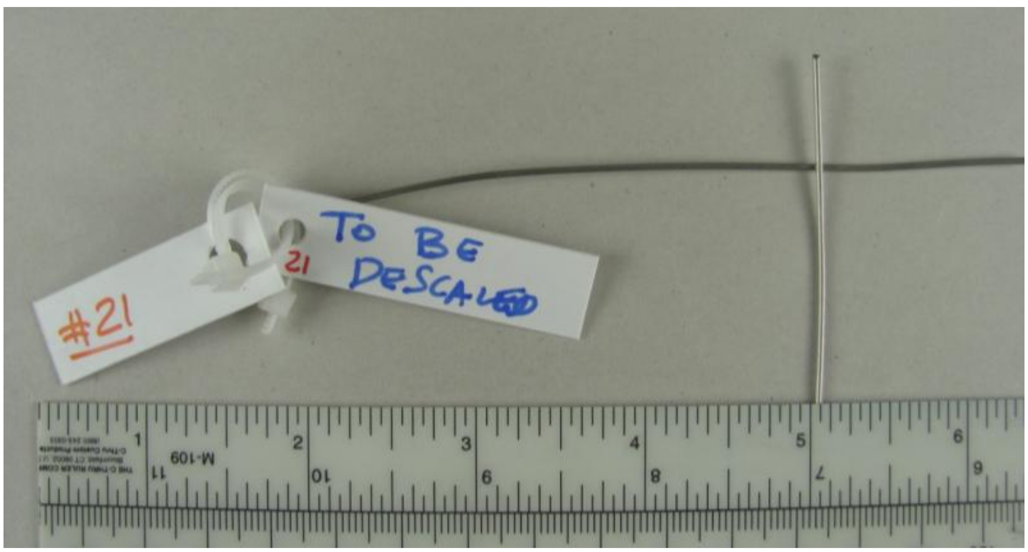


Macro photograph showing Sample #14 made from Type 317L stainless steel shown prior to descale / passivation and salt spray testing.

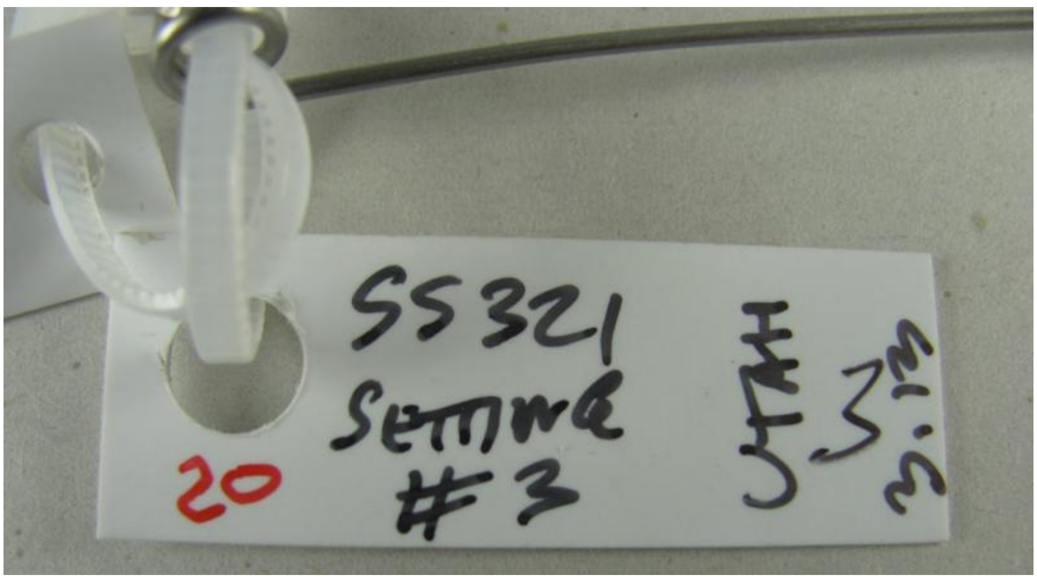


Macro photographs showing the as-received appearance of the Type 321 solid wire weld samples prior to descale /passivation and salt spray testing. Sample # 17, #18, #19, #20 and #21 are shown.

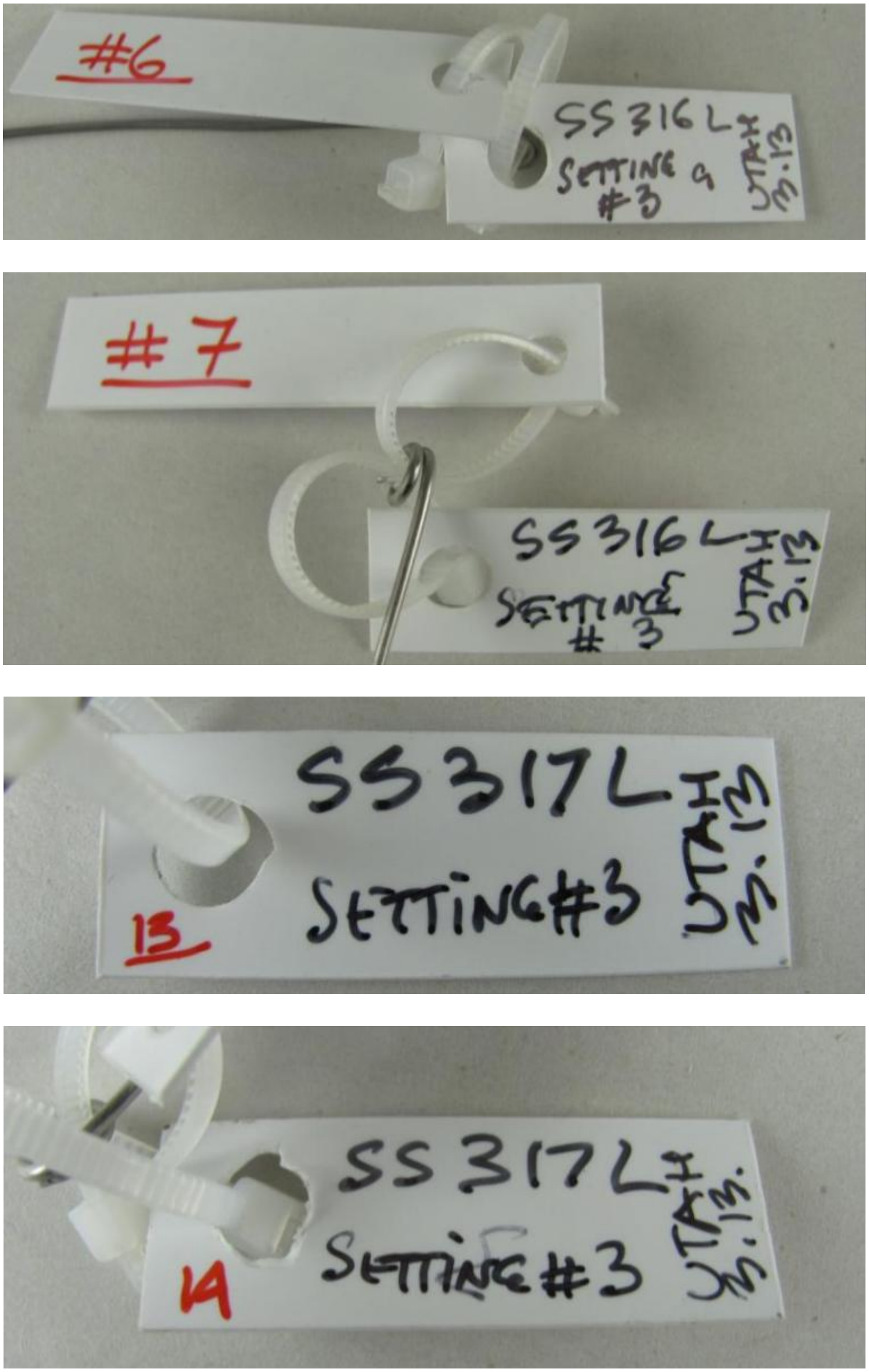




Macro photographs showing the as-received appearance of the Type 321 solid wire weld samples prior to descale / passivation and salt spray testing. Sample # 20 and #21 are shown.



Close-up photographs showing the tags on Sample #20 and #21. These two samples were made from Type 321 stainless steel and are shown prior to being descaled and passivated.

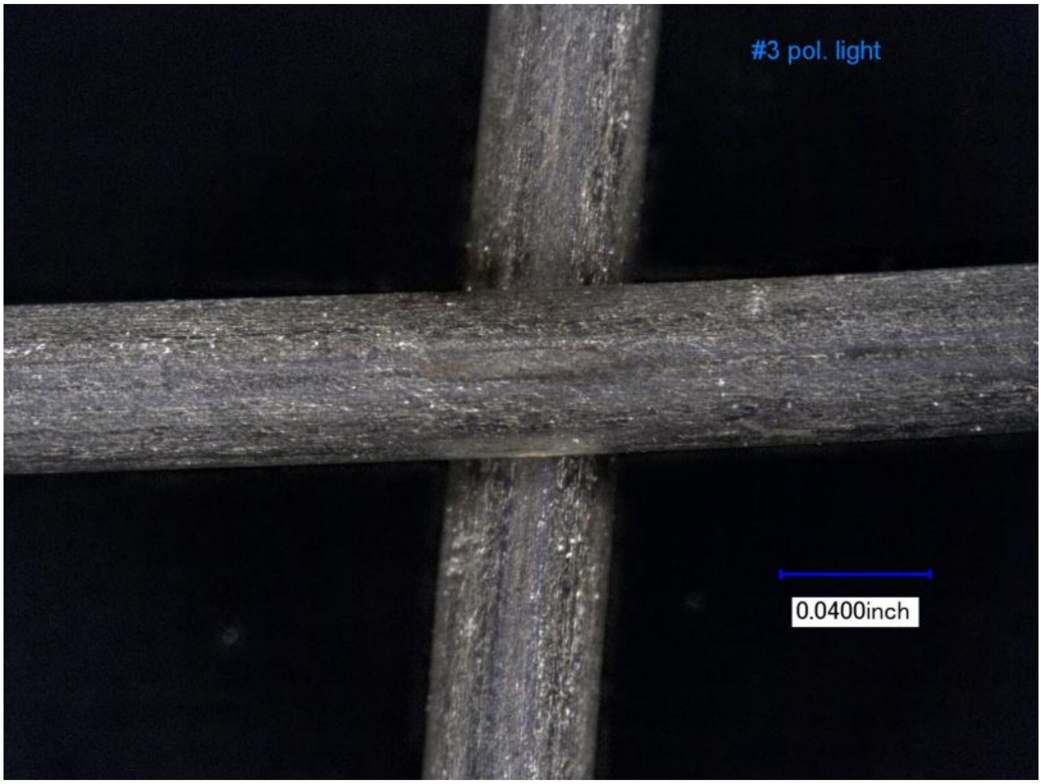


Close-up photographs showing the tags on Sample #6, Sample #7 (Type 316L stainless steel) along with the tags from Sample #13 and Sample #14 (Type 317L stainless steel).

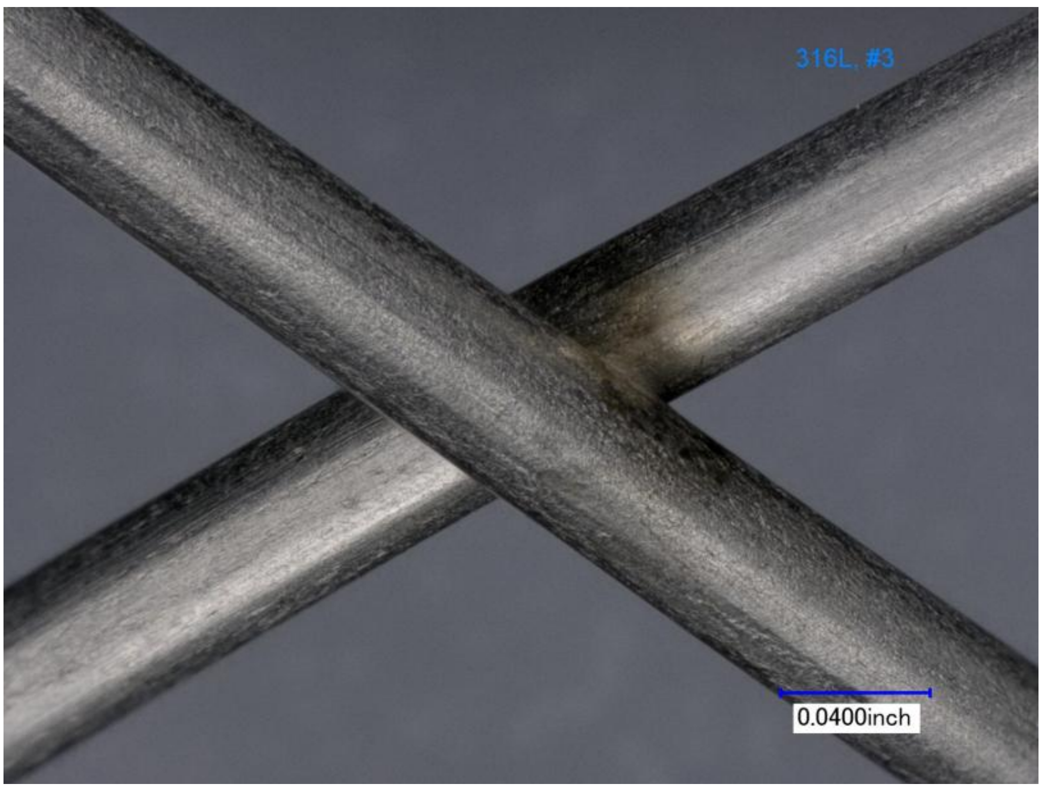
Type 316L Solid Wire Samples Prior to 1000 Hour Environmental Exposure

Samples #3, #4 & #5

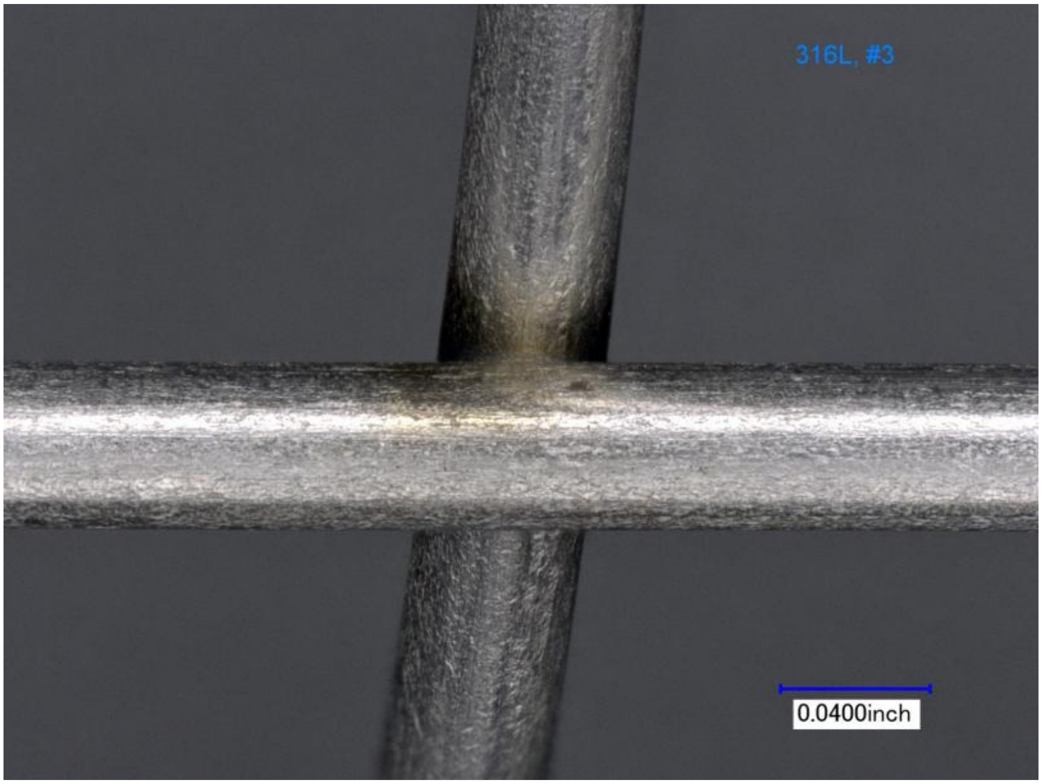
It should be noted that variations in the wire reflectivity can be the result of the particular lighting conditions used to take the image. Images were taken using polarized light as well as with numerous diffusers in order to capture the most detail possible hence some of the images may appear darker and or lighter than others.



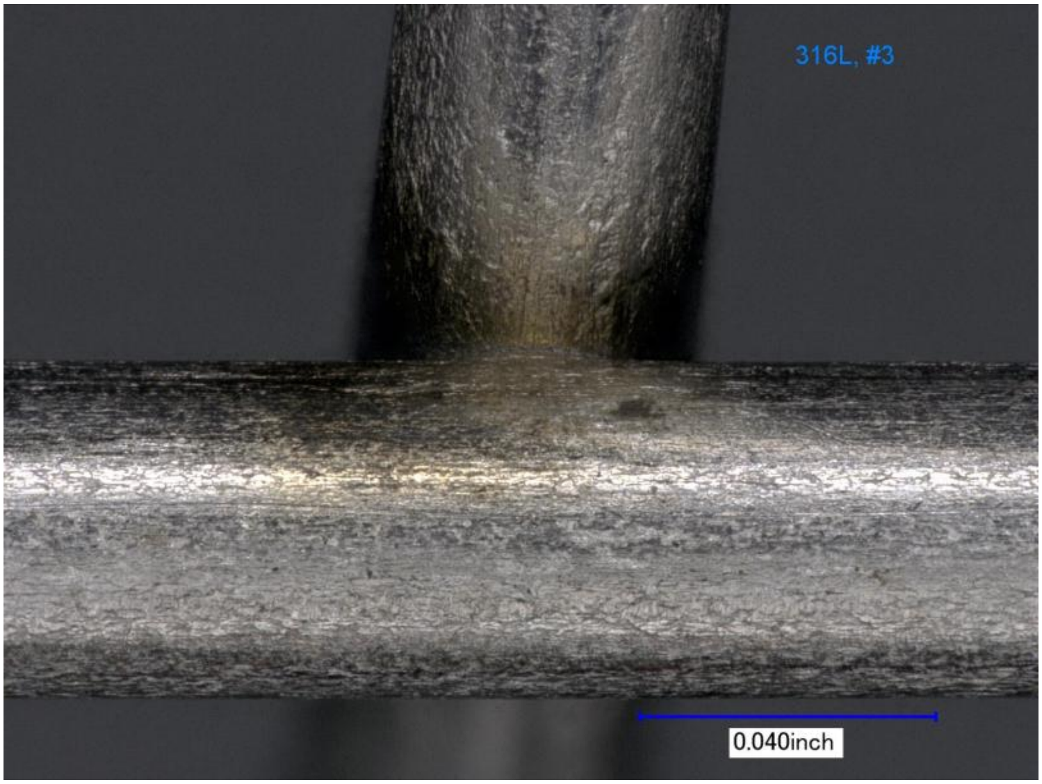
Sample #3-1.jpg



Sample #3-2.jpg

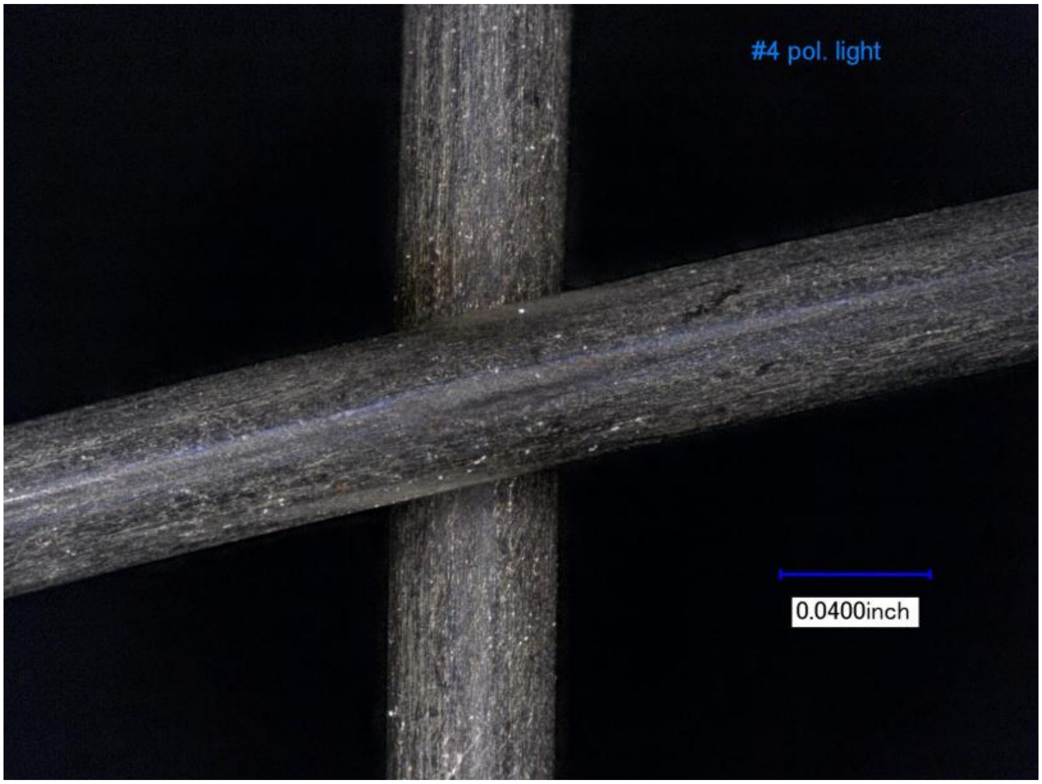


Sample #3-3.jpg

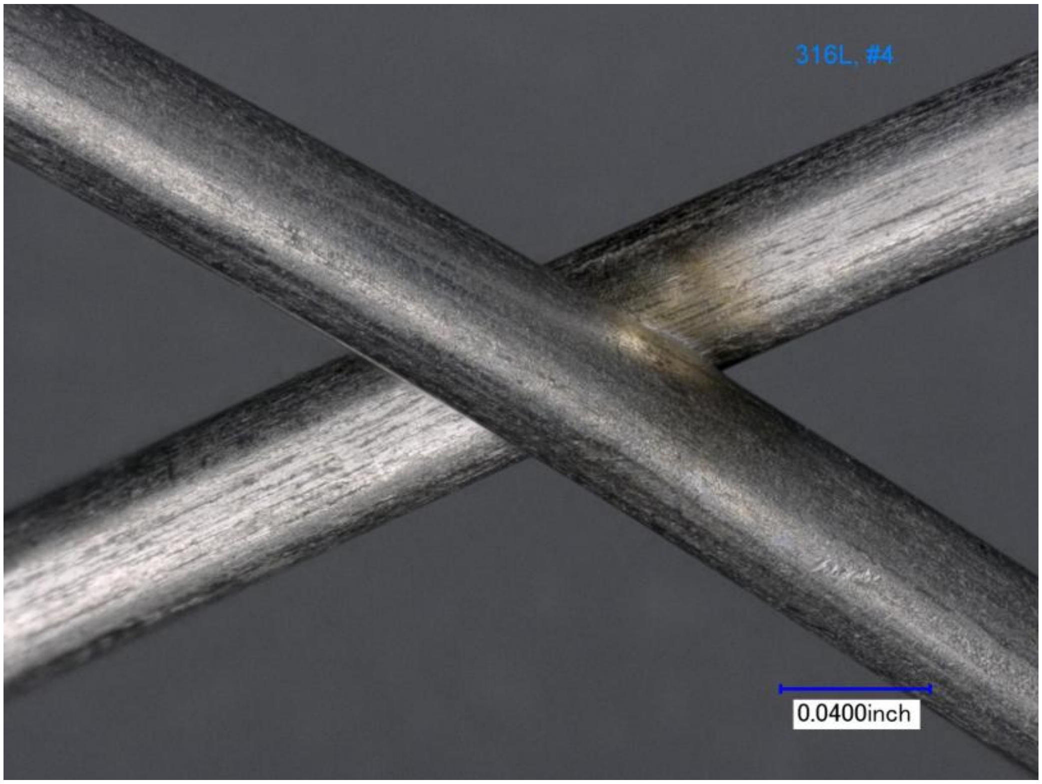


Sample #3-3b.jpg

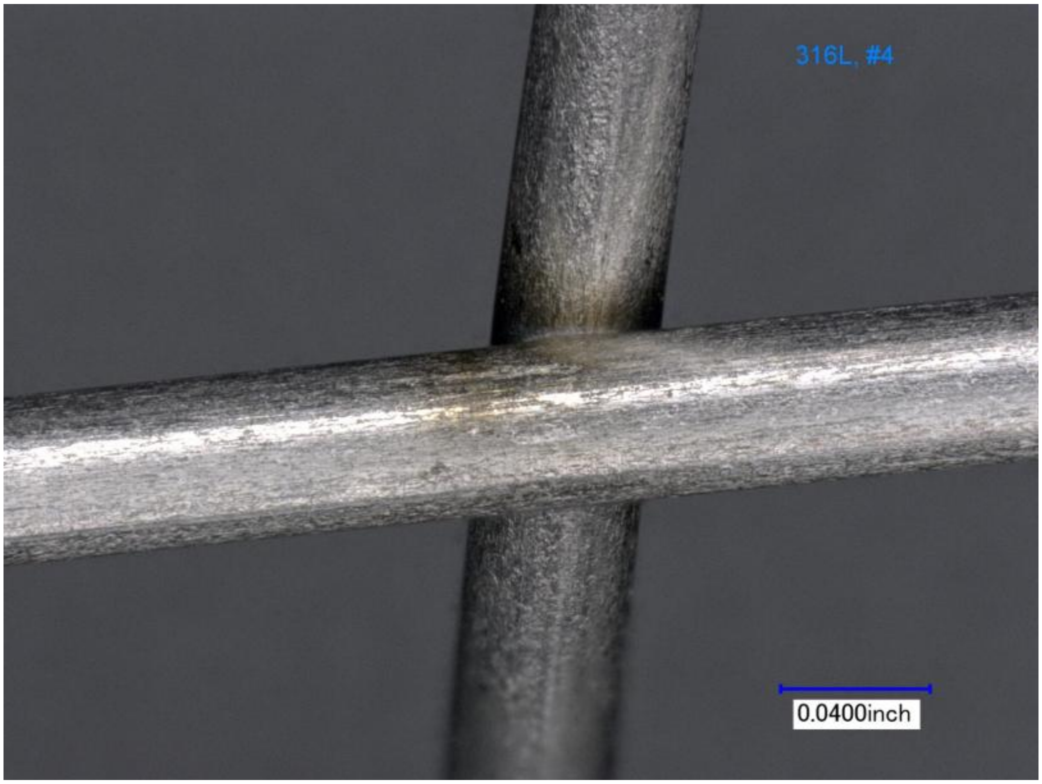
Sample #3-4.jpg



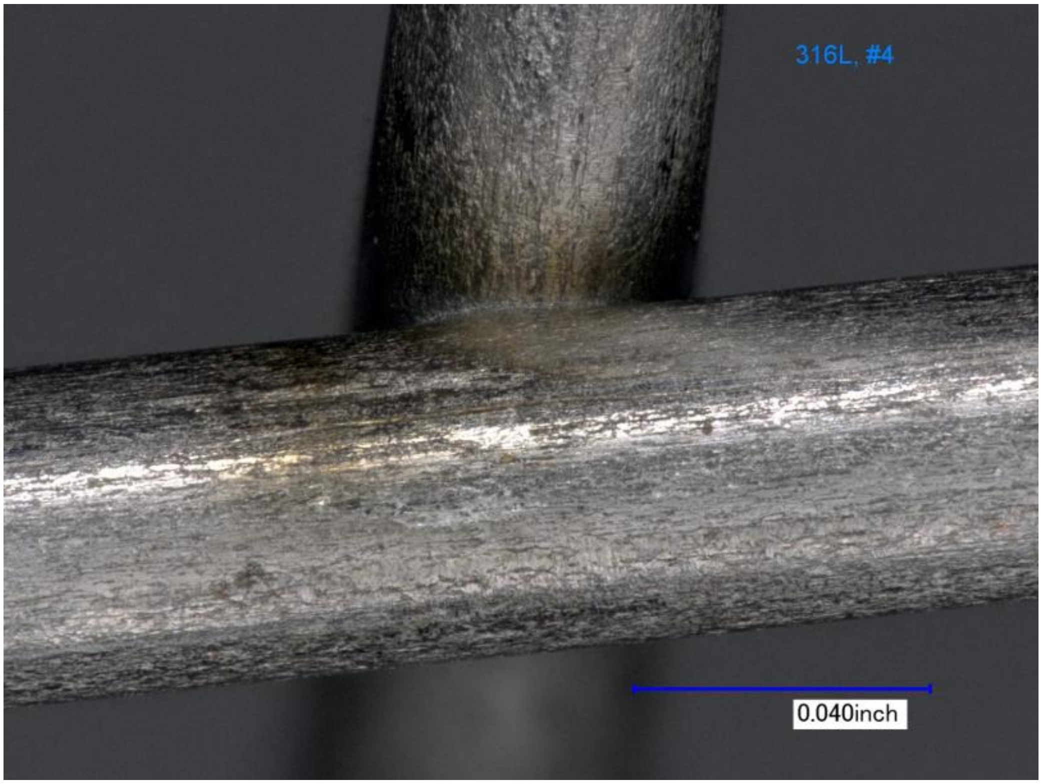
Sample #4-1.jpg



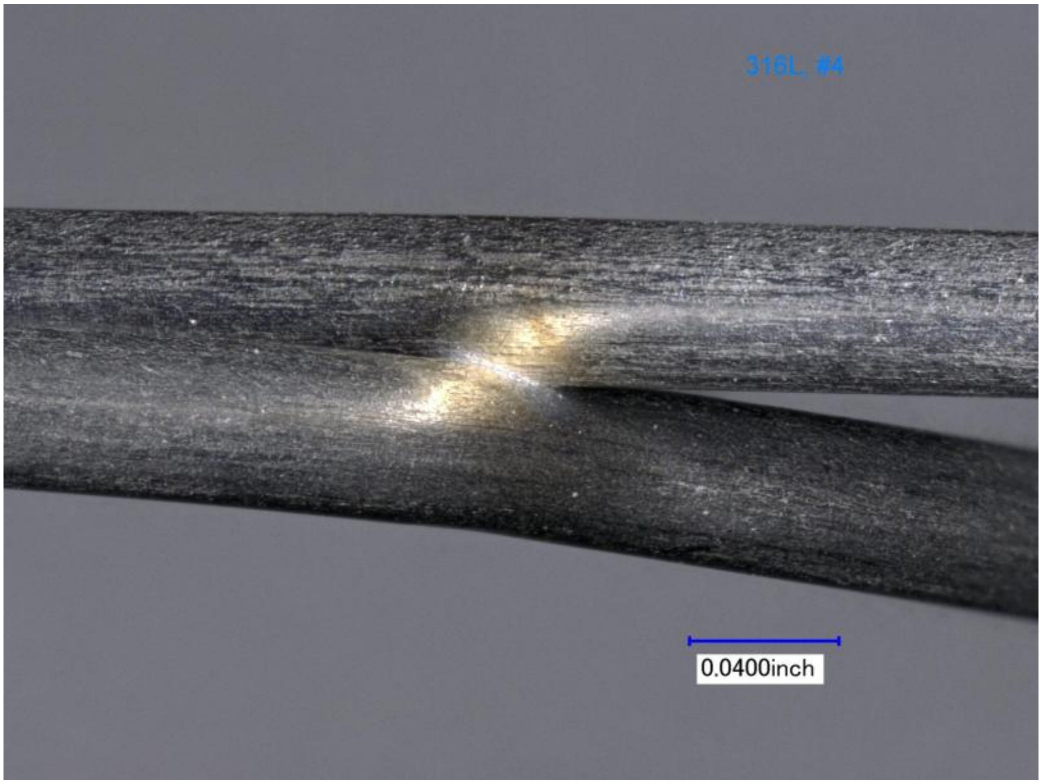
Sample #4-2.jpg



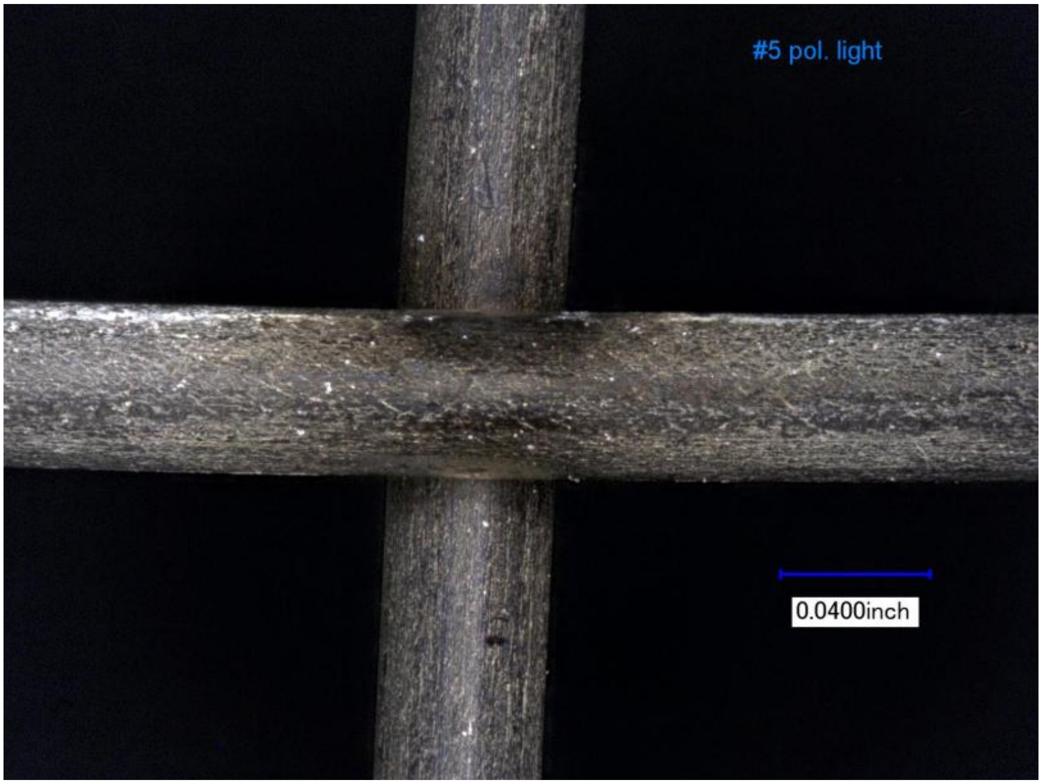
Sample #4-3.jpg



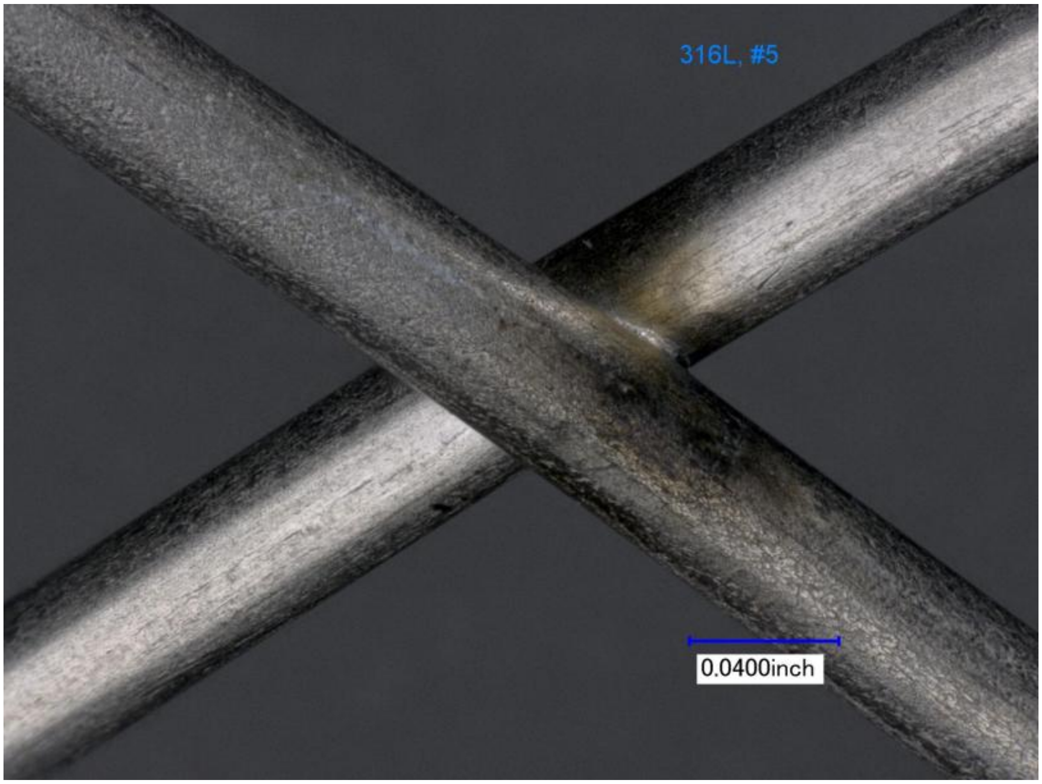
Sample #4-3b.jpg



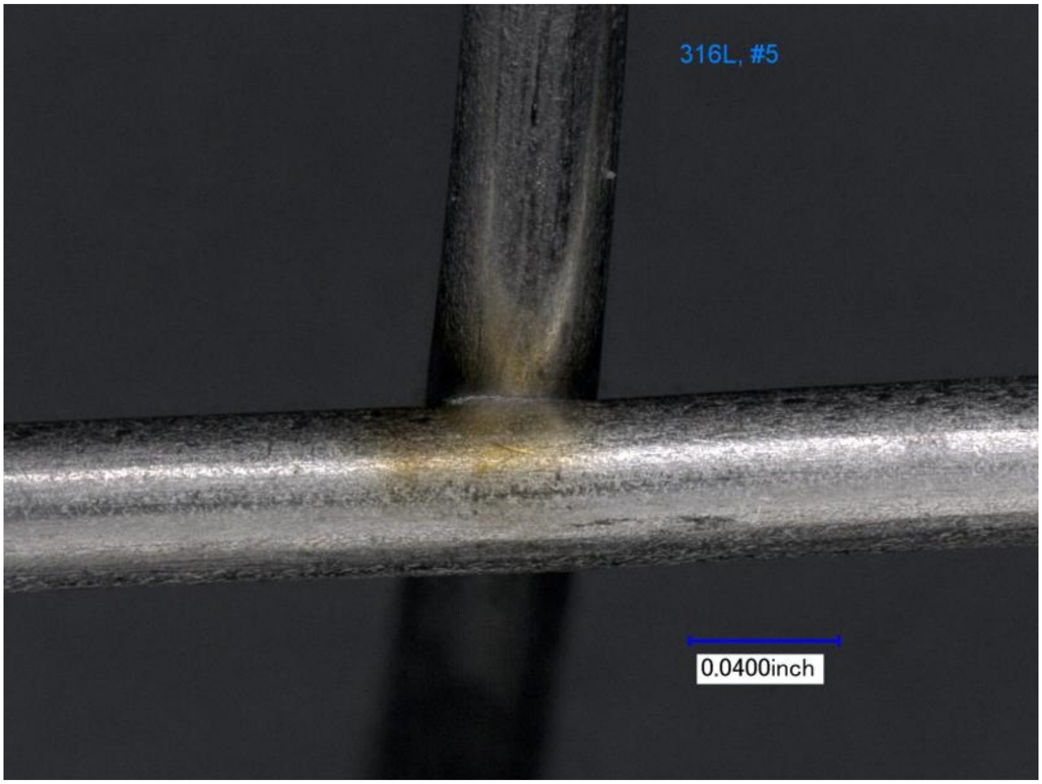
Sample #4-4.jpg



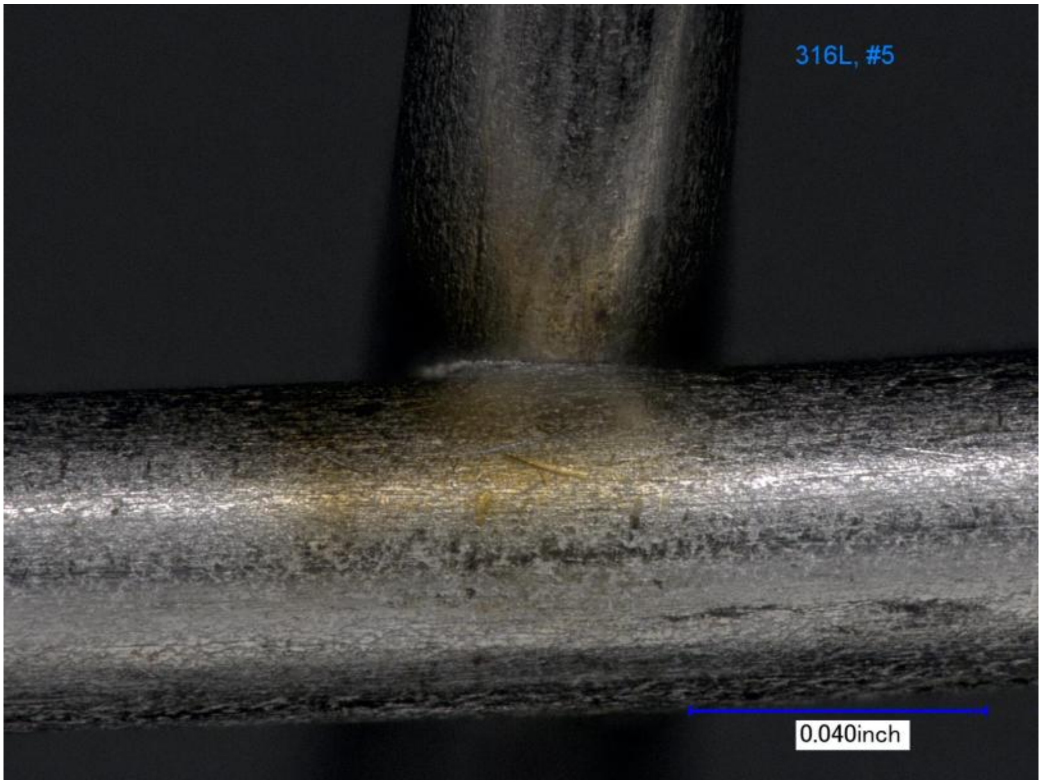
Sample #5-1.jpg



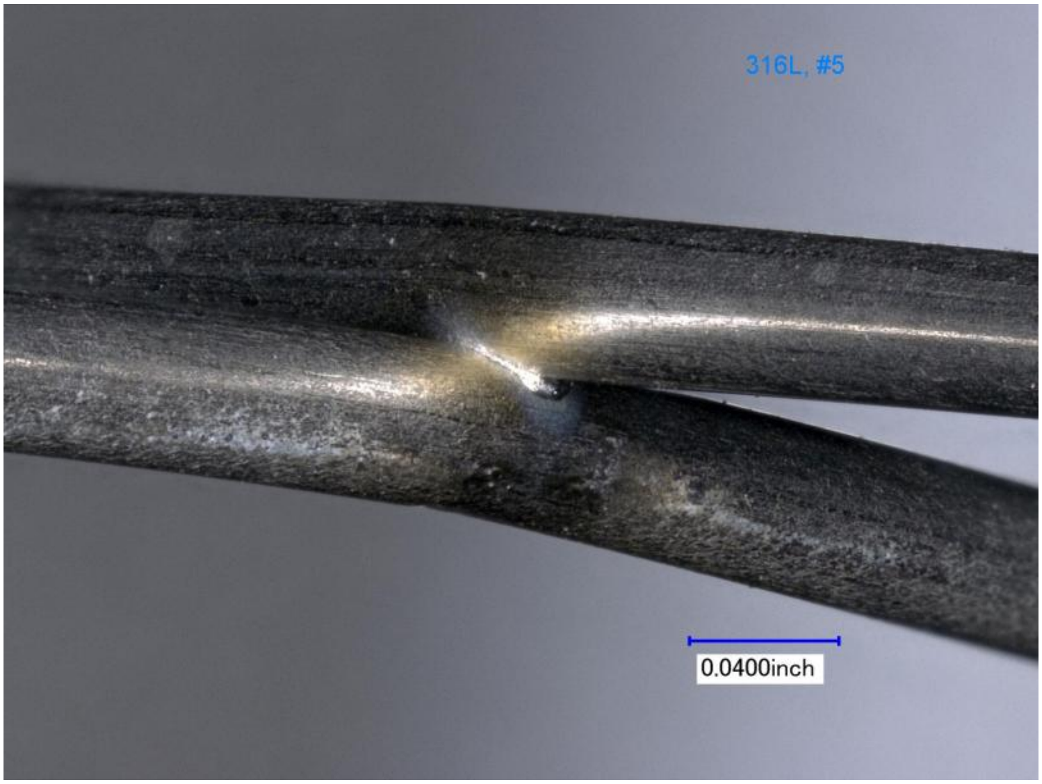
Sample #5-2.jpg



Sample #5-3.jpg



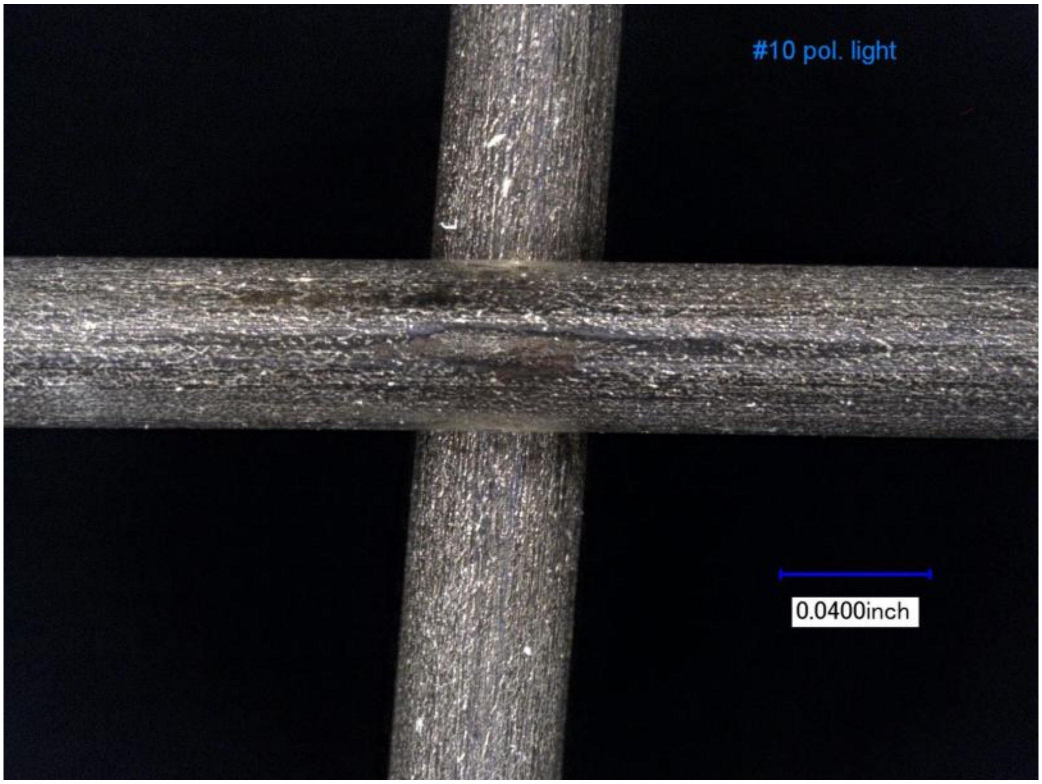
Sample #5-3b.jpg



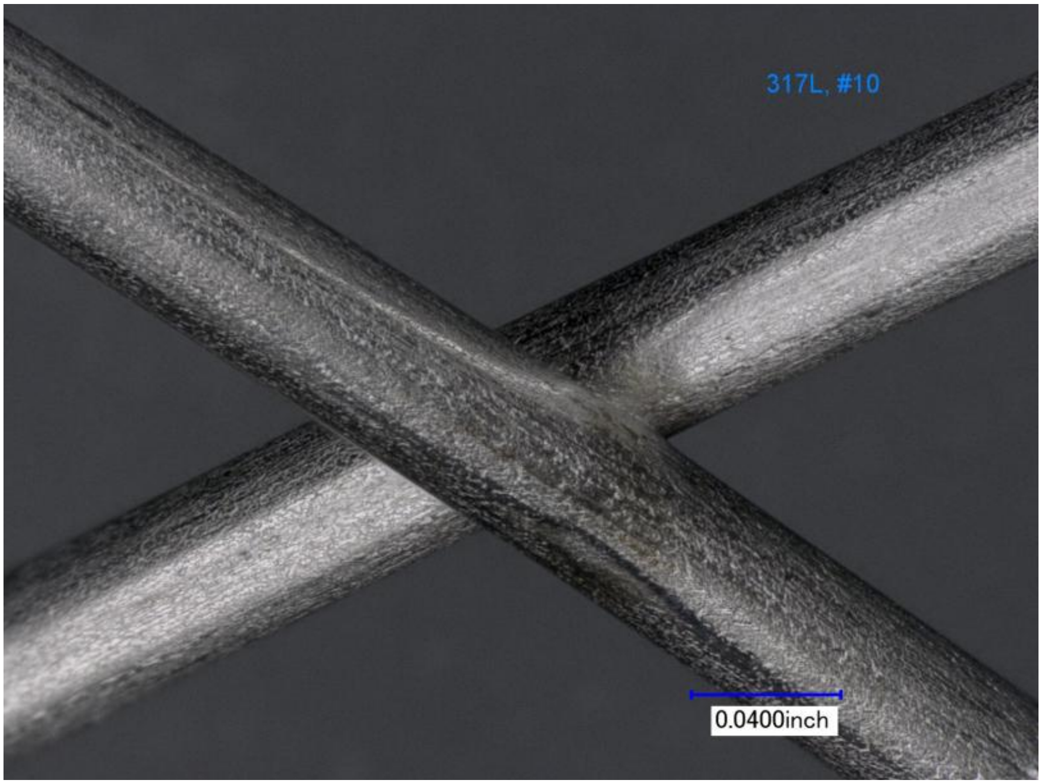
Sample #5-4.jpg

Type 317L Solid Wire Samples Prior to 1000 Hour Environmental Exposure

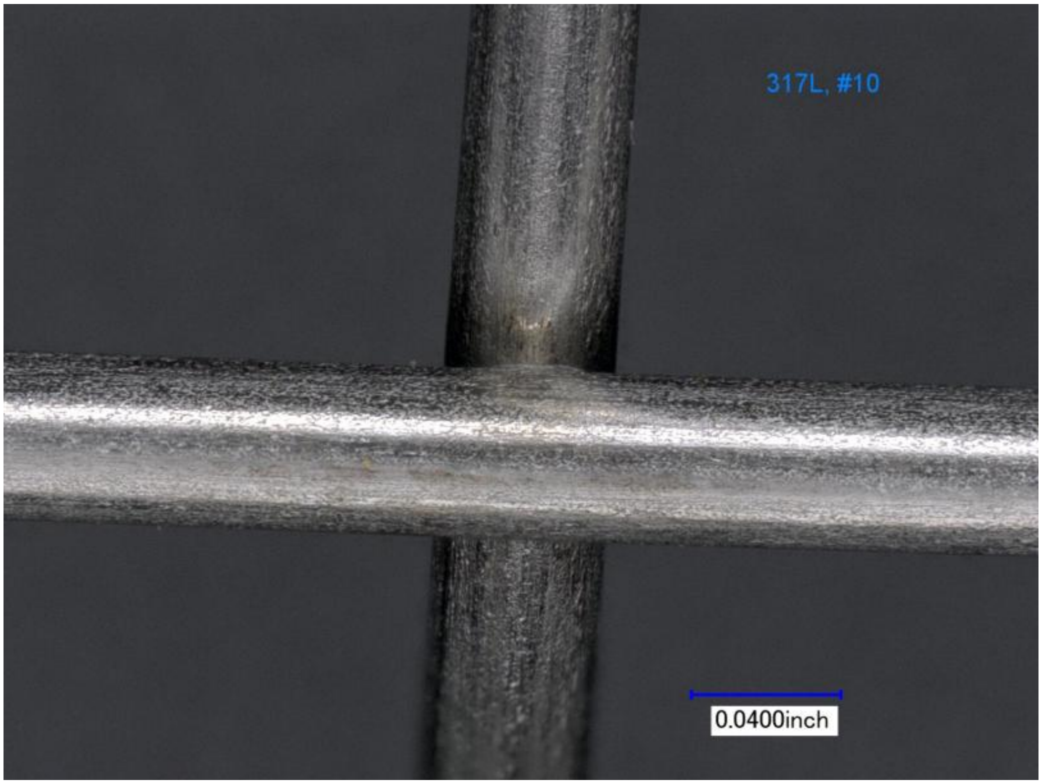
Samples #10, #11 & #12



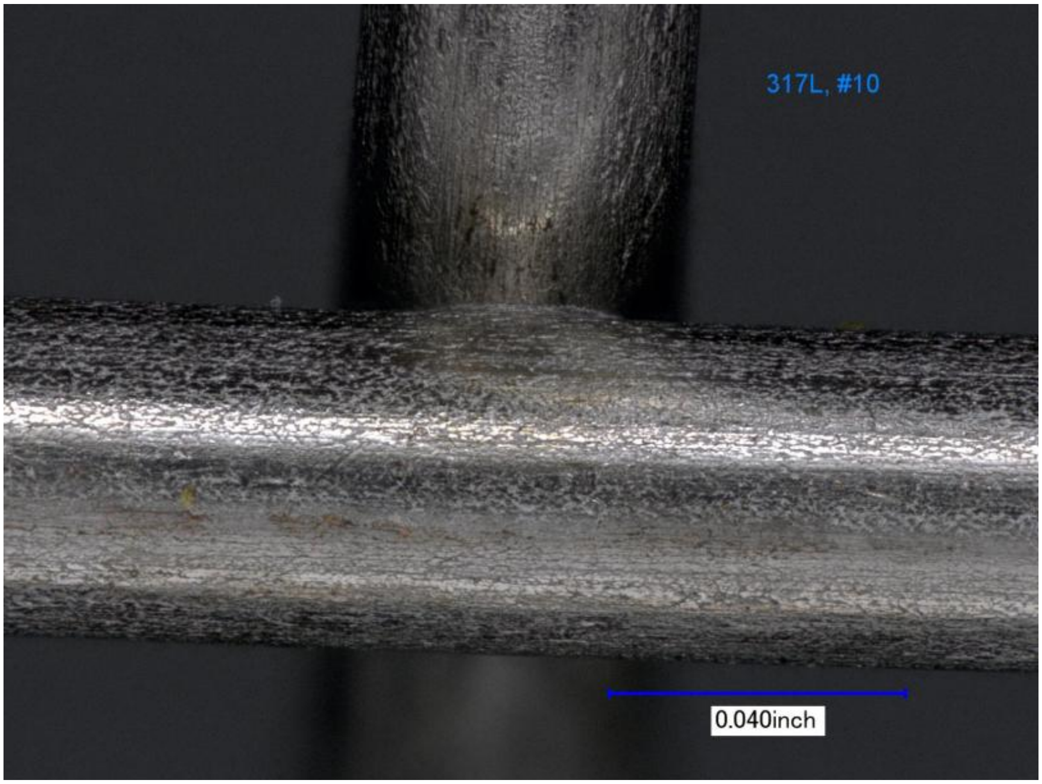
Sample #10 - 1.jpg



Sample #10 - 2.jpg



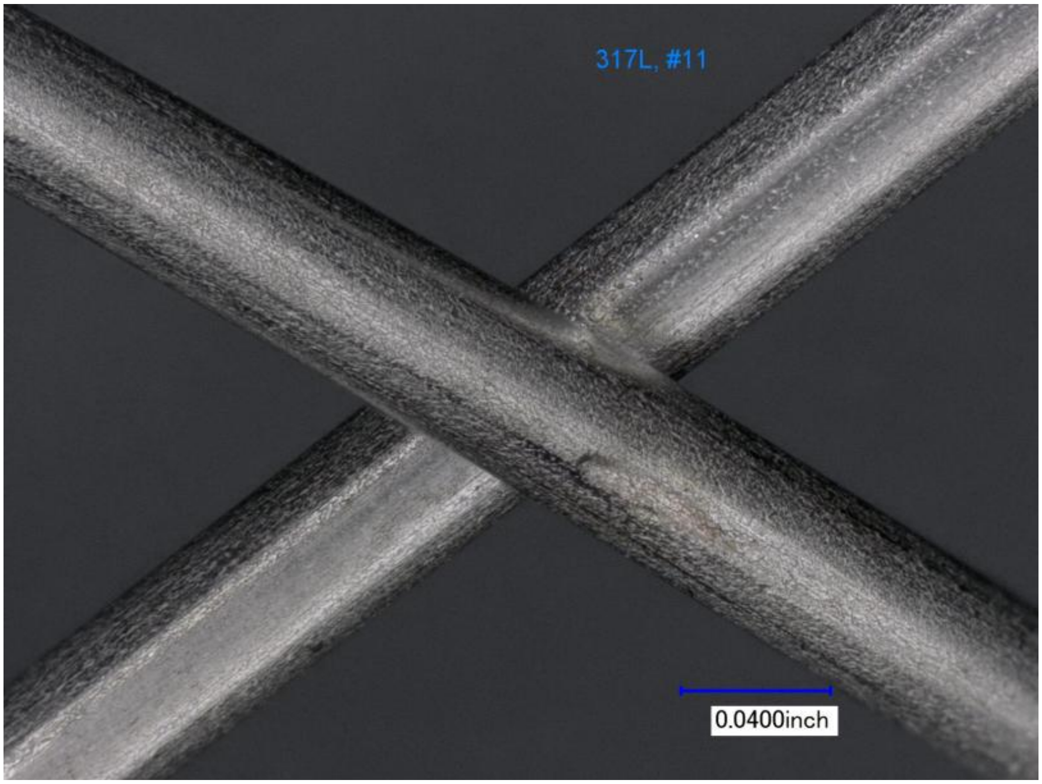
Sample #10 - 3.jpg



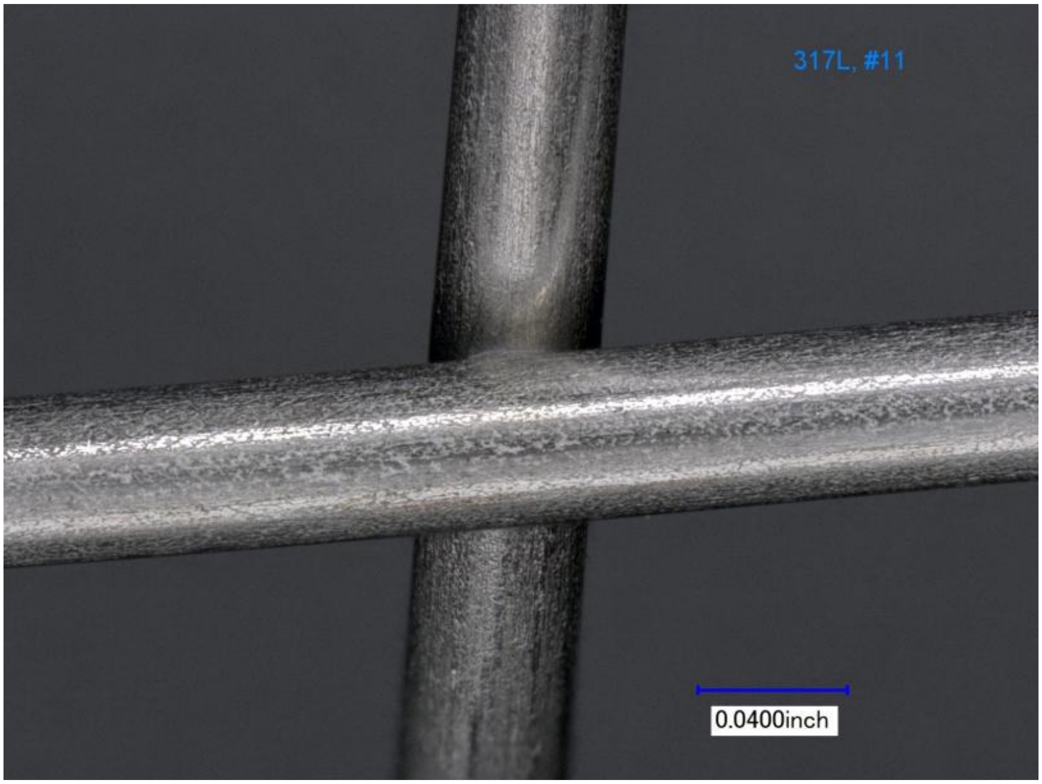
Sample #10 - 3b.jpg

Sample #10 - 4.jpg

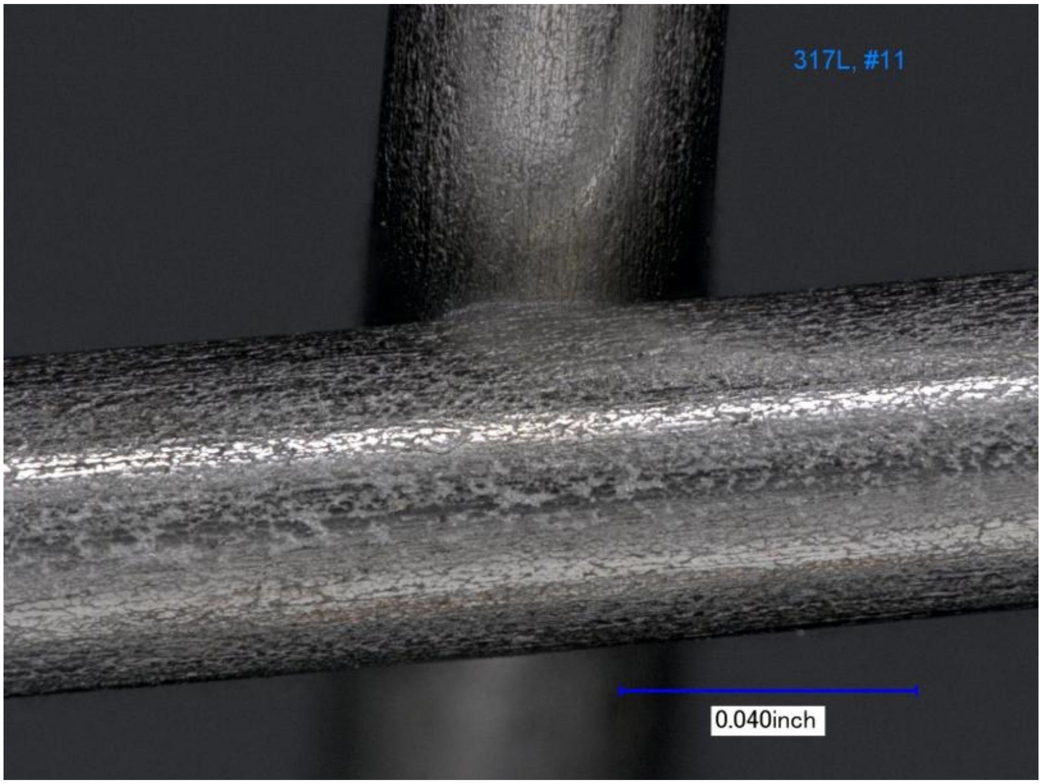
Sample #11 - 1.jpg



Sample #11 - 2.jpg



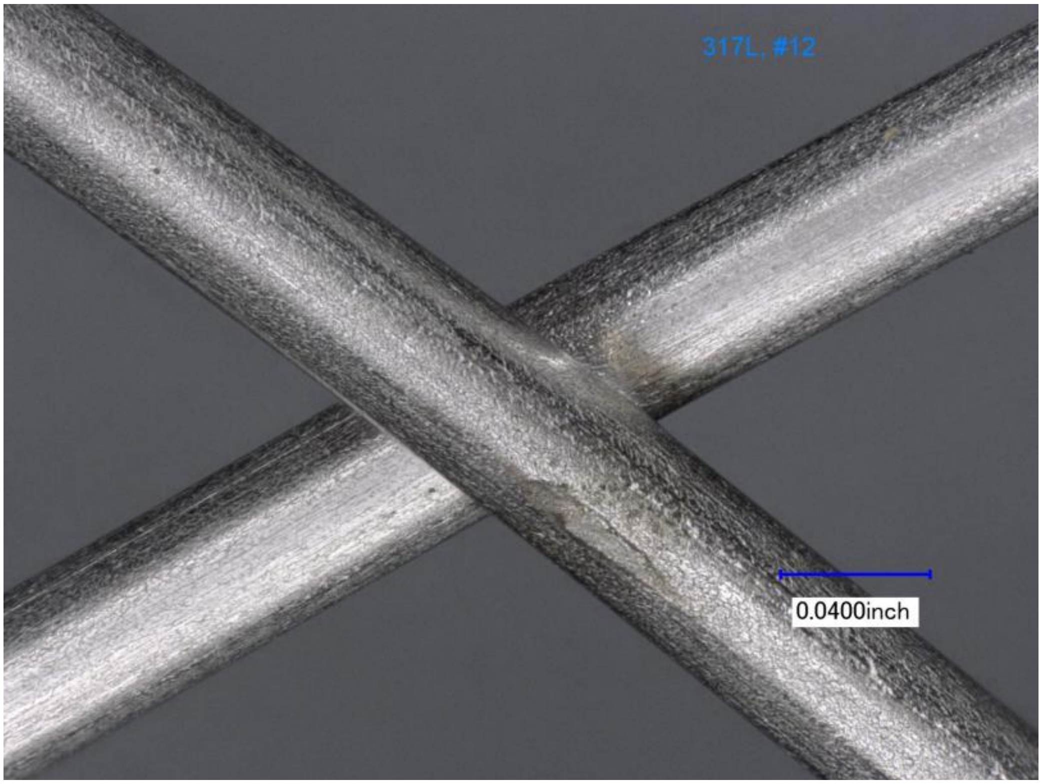
Sample #11 - 3.jpg



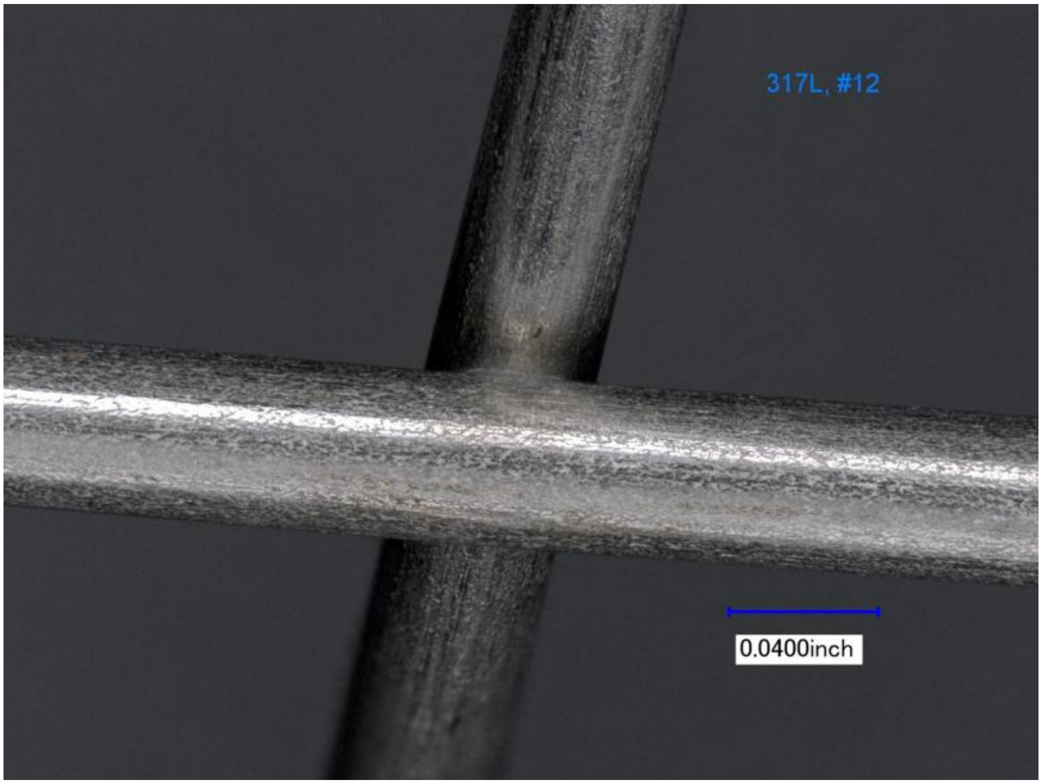
Sample #11 - 3b.jpg

Sample #11 - 4.jpg

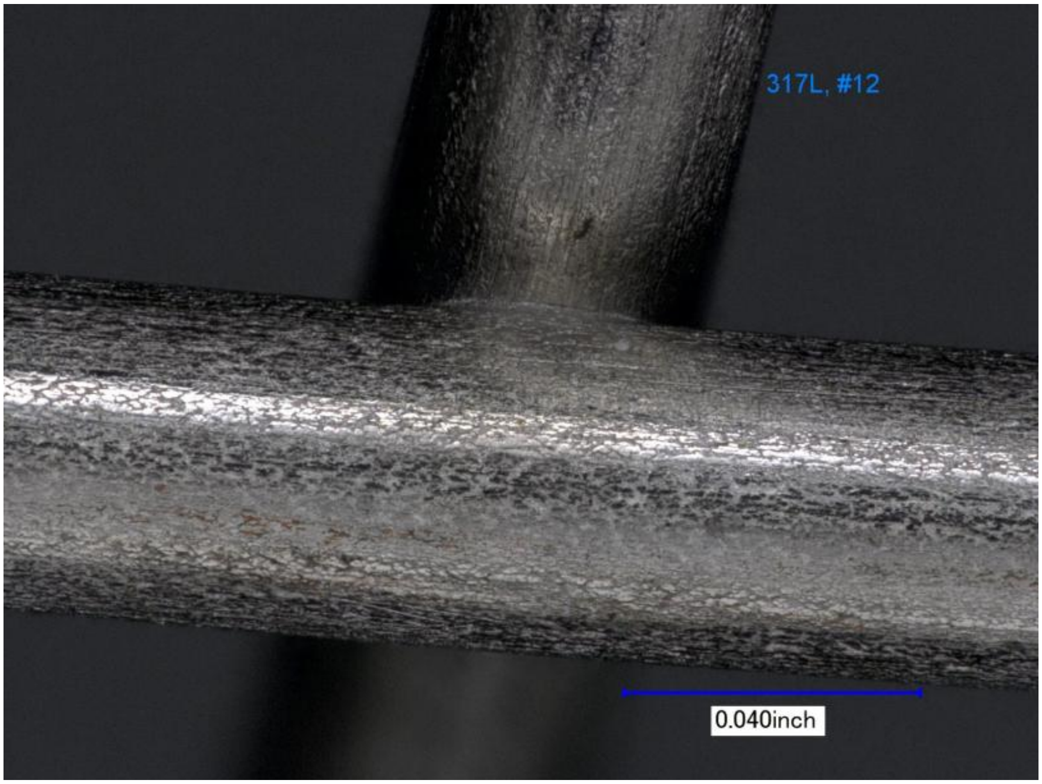
Sample #12 - 1.jpg



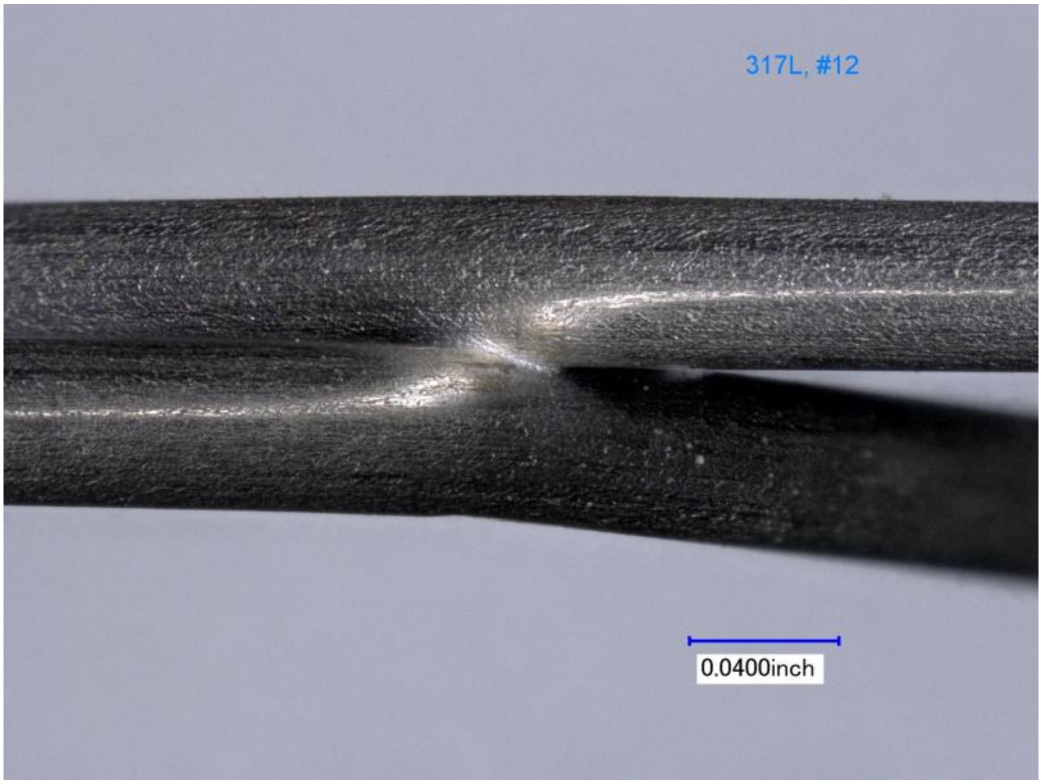
Sample #12 - 2.jpg



Sample #12 - 3.jpg



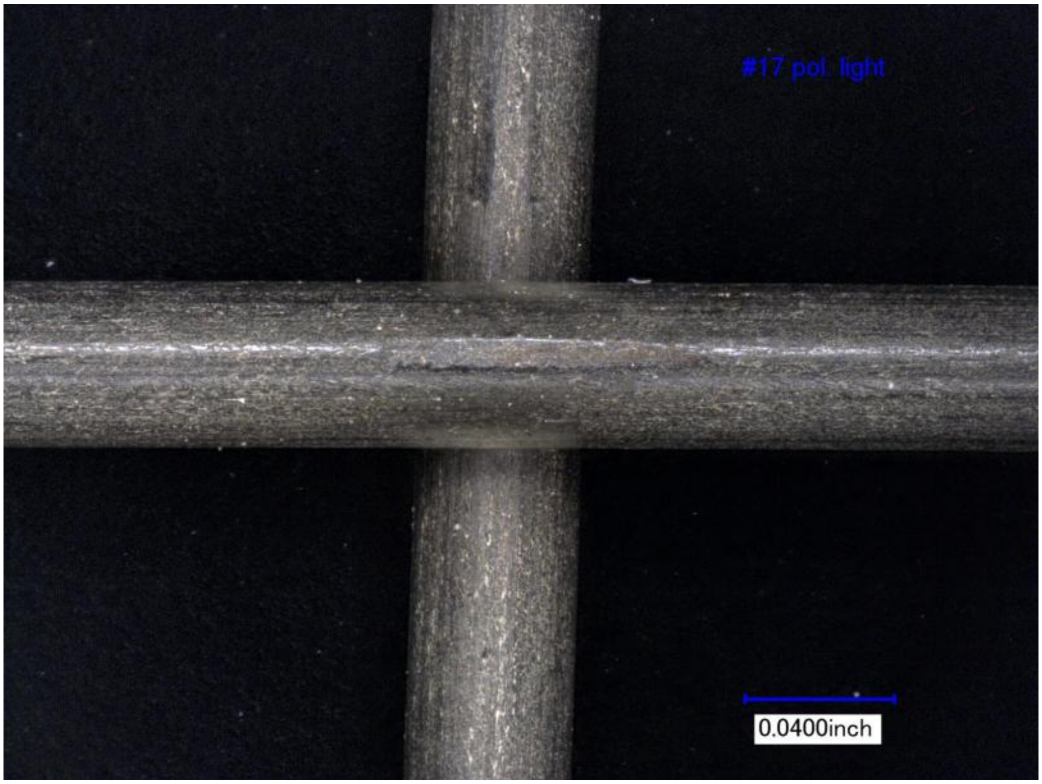
Sample #12 - 3b.jpg



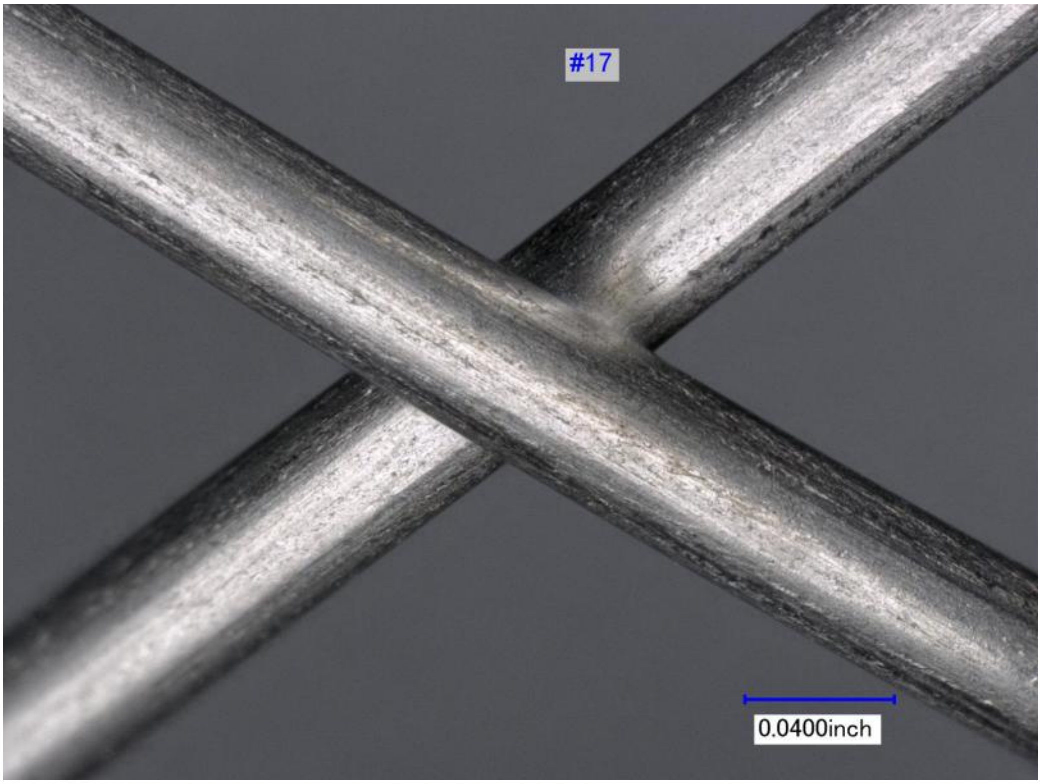
Sample #12 - 4.jpg

Type 321 Solid Wire Samples Prior to 1000 Hour Environmental Exposure

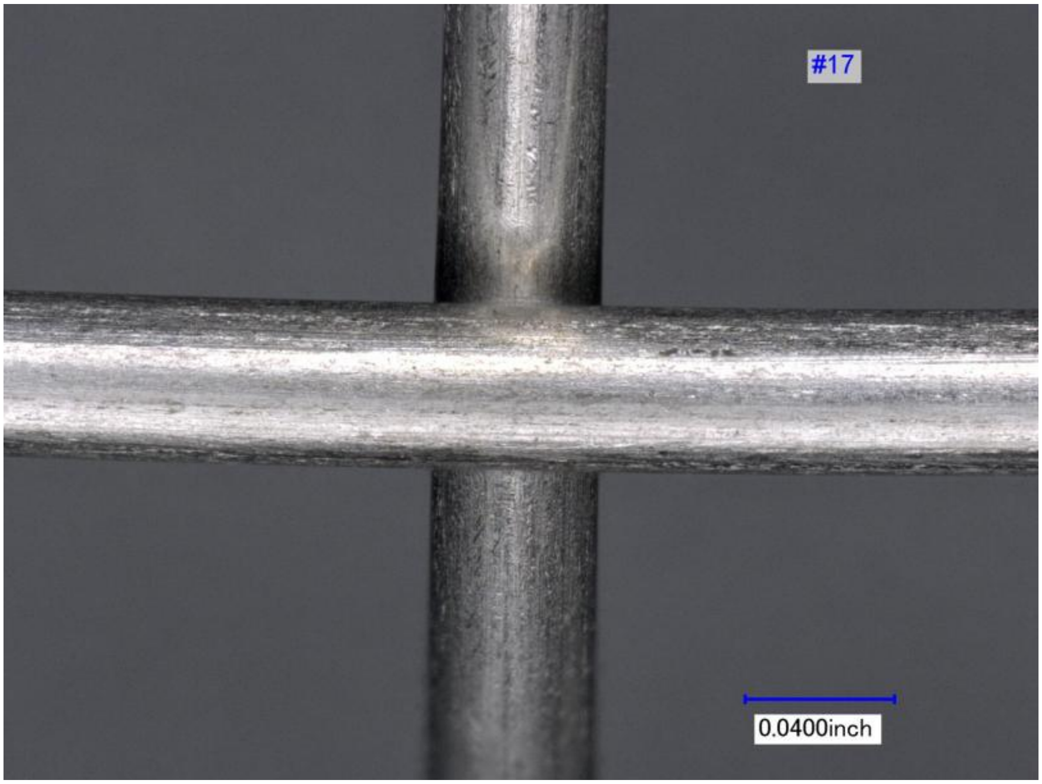
Samples #17, #18 & #19



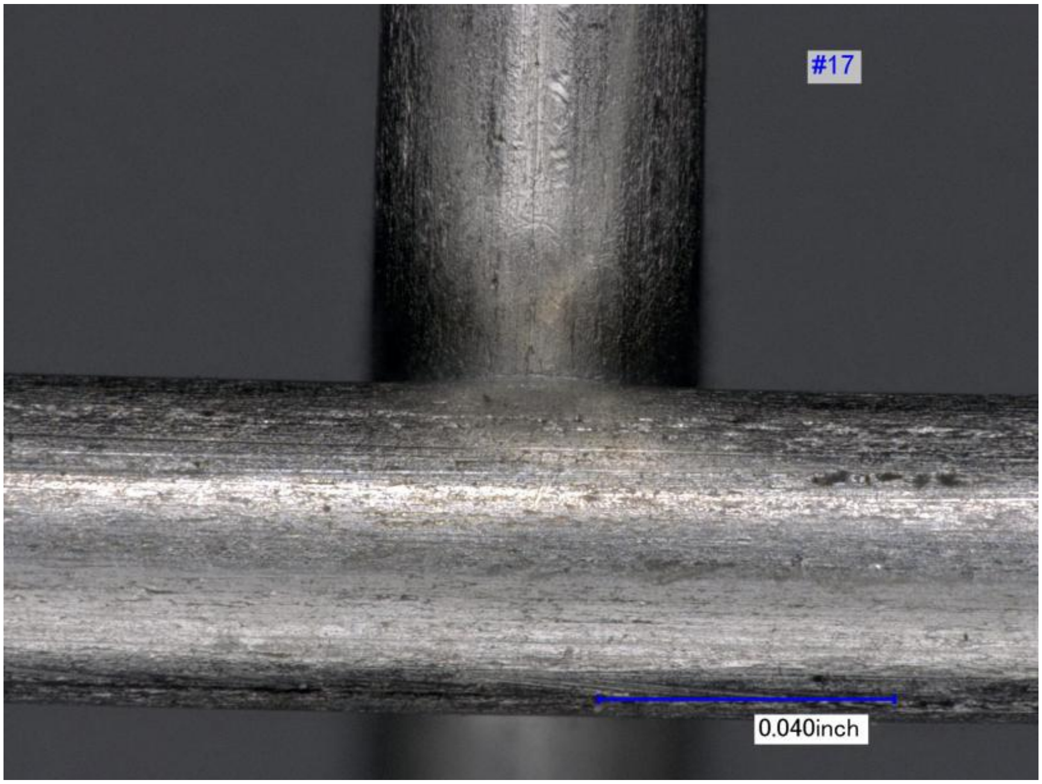
Sample #17 - 1.jpg



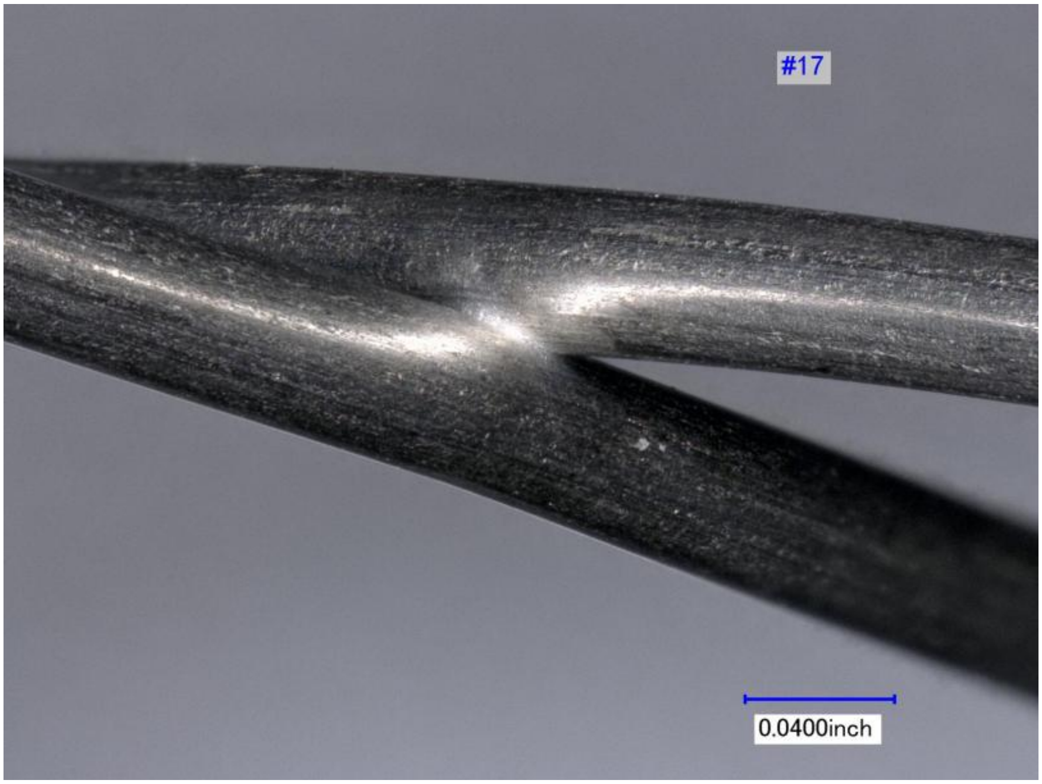
Sample #17 - 2.jpg



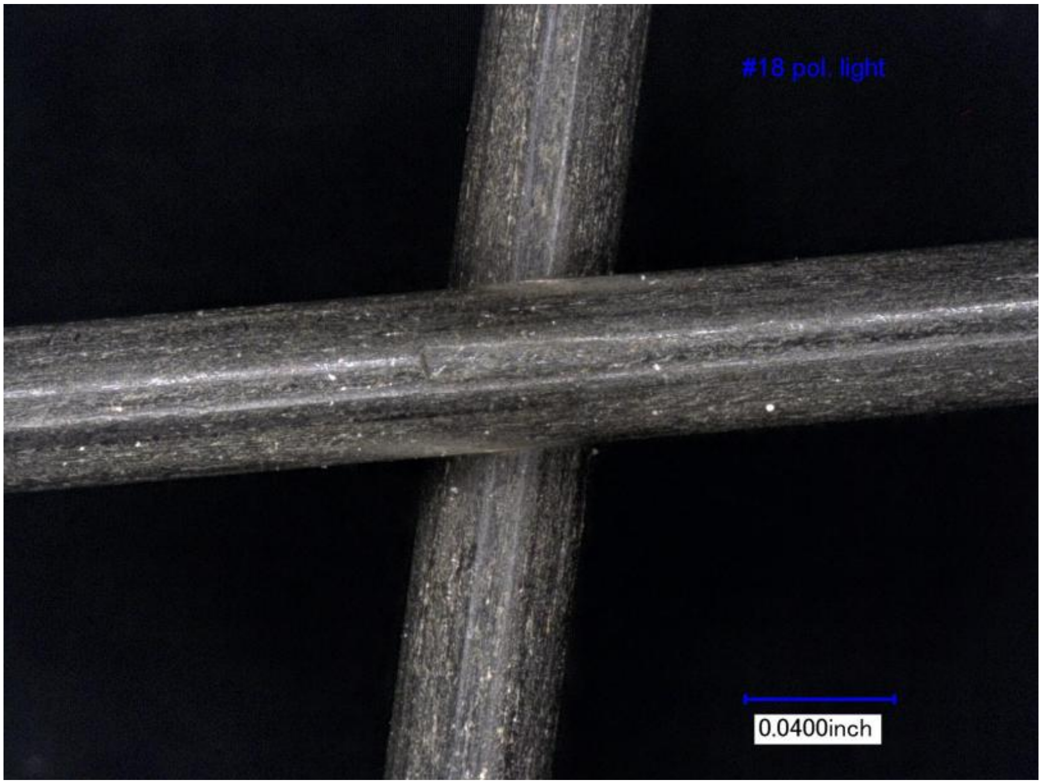
Sample #17 - 3.jpg



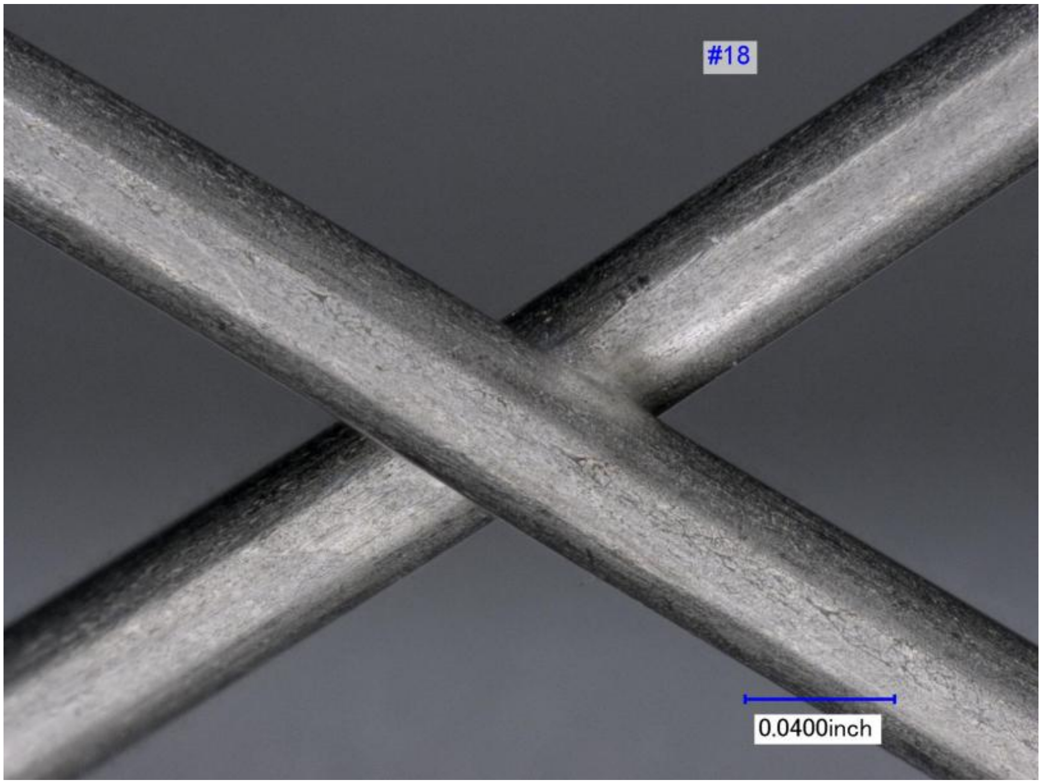
Sample #17 - 3b.jpg



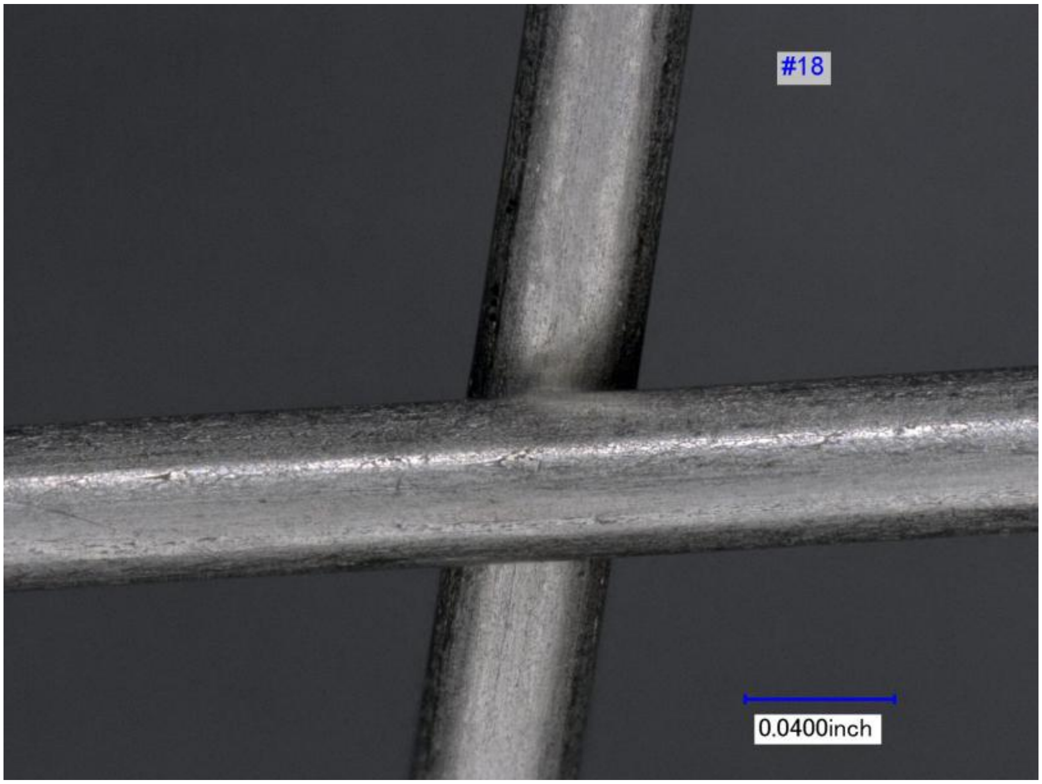
Sample #17 - 4.jpg



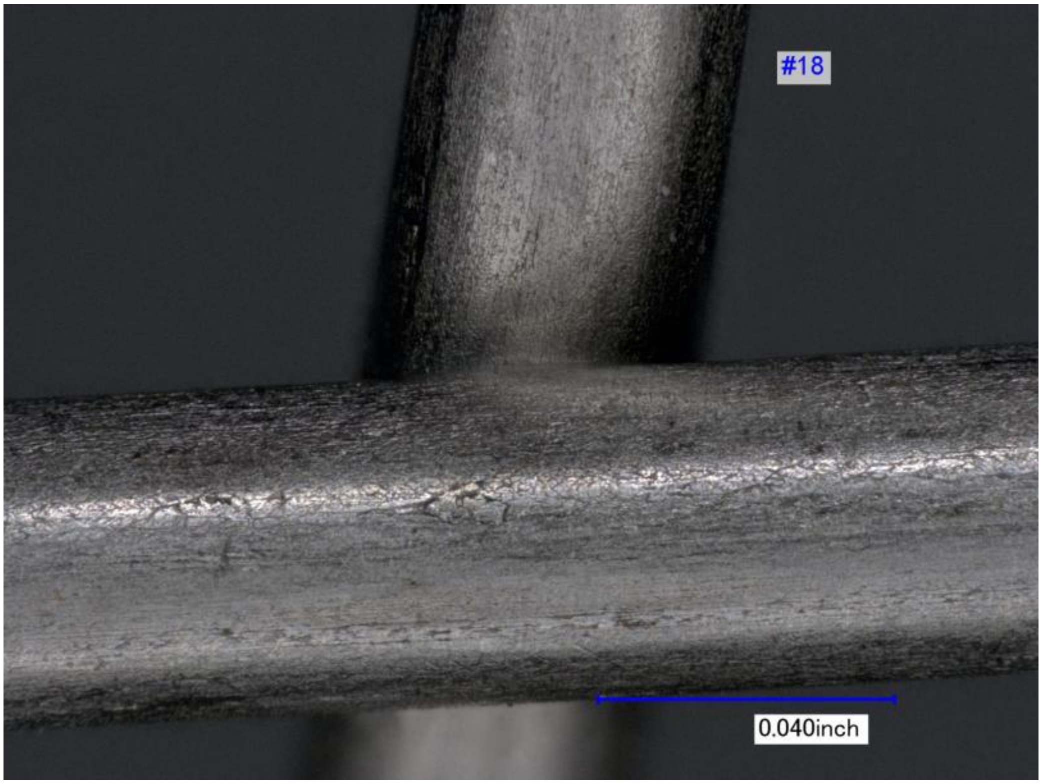
Sample #18 - 1.jpg



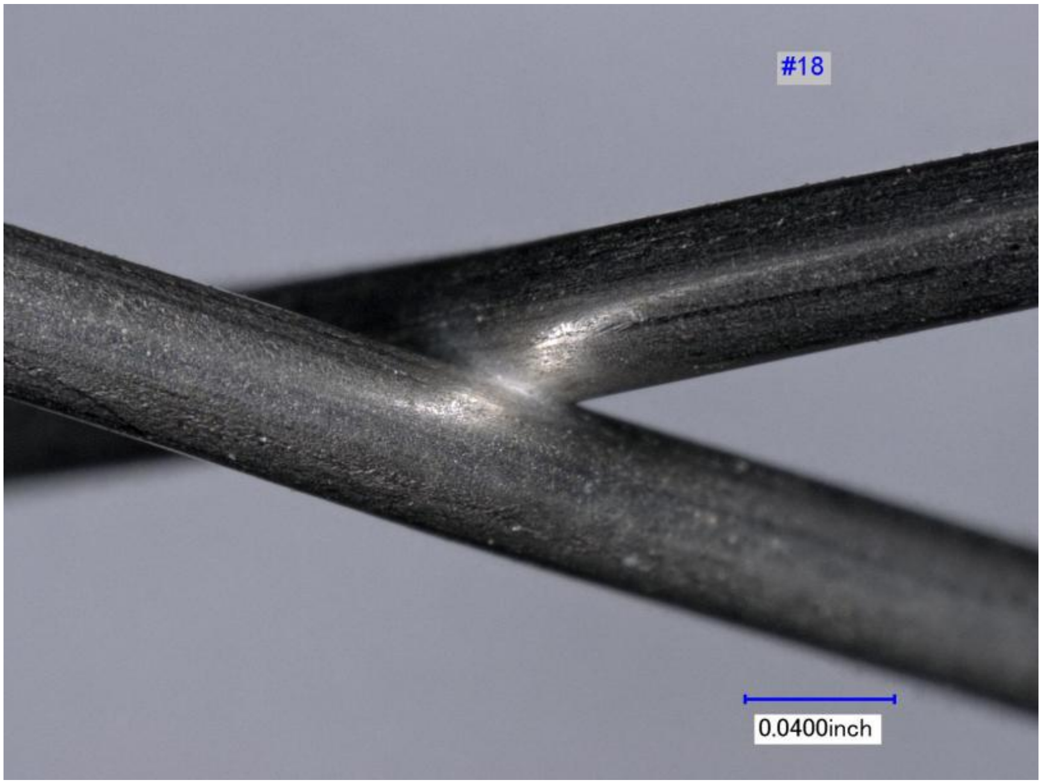
Sample #18 - 2.jpg



Sample #18 - 3.jpg

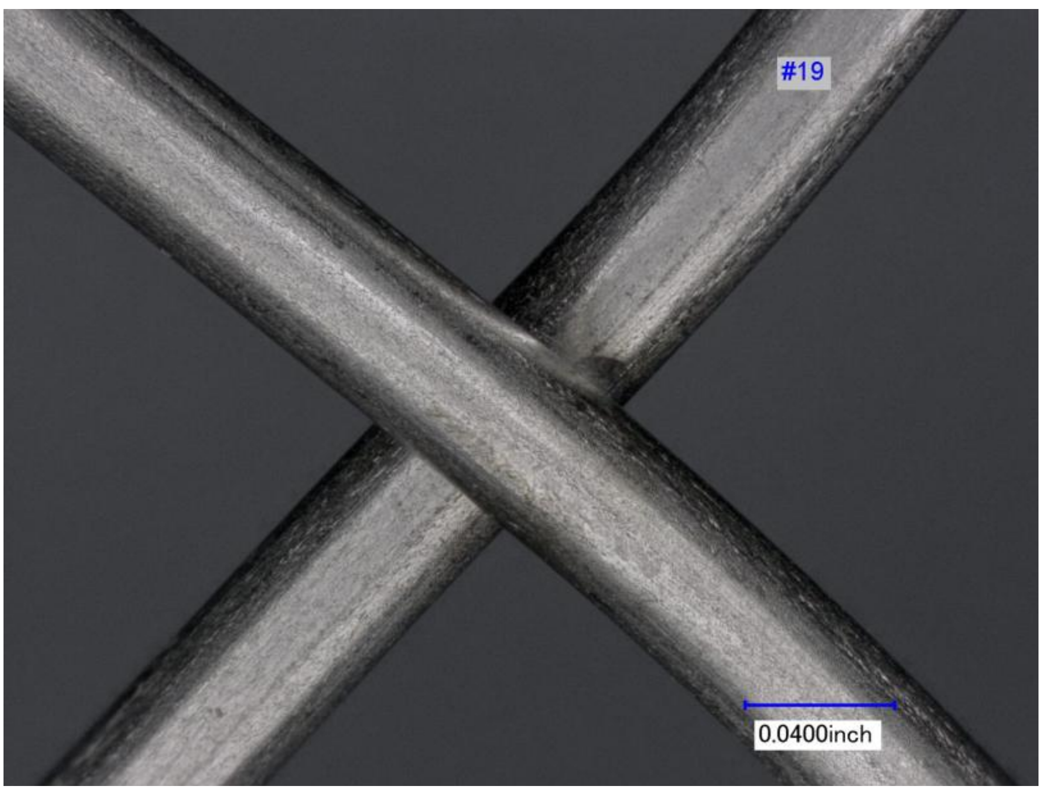


Sample #18 - 3b.jpg

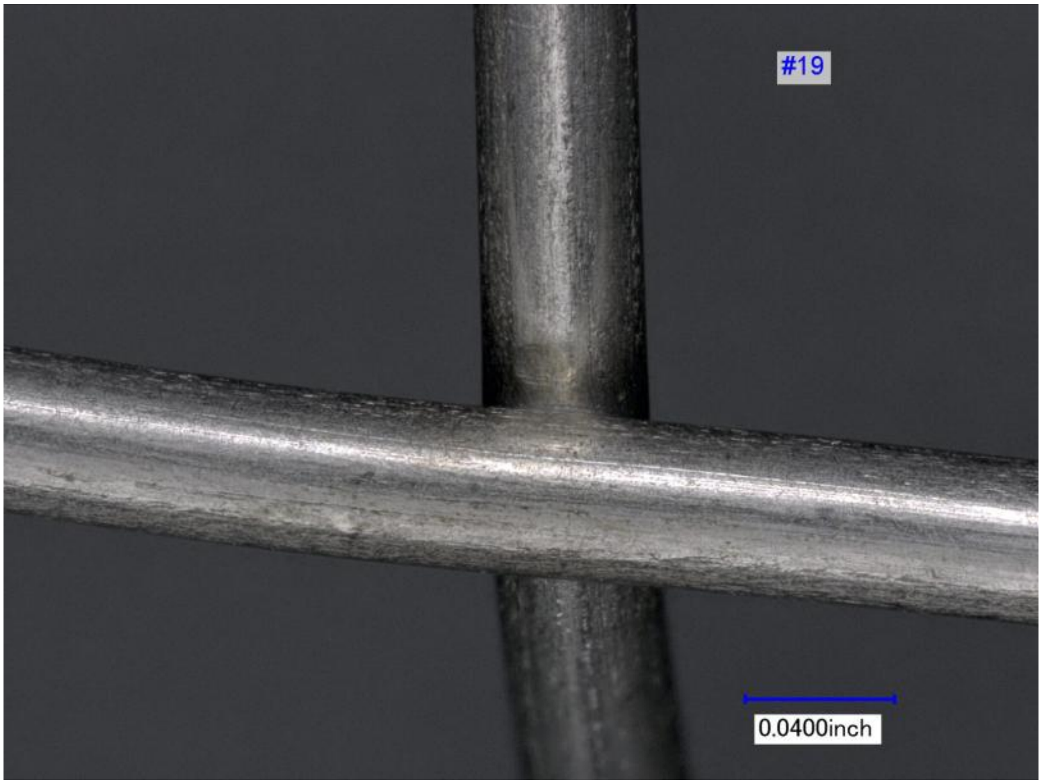


Sample #18 - 4.jpg

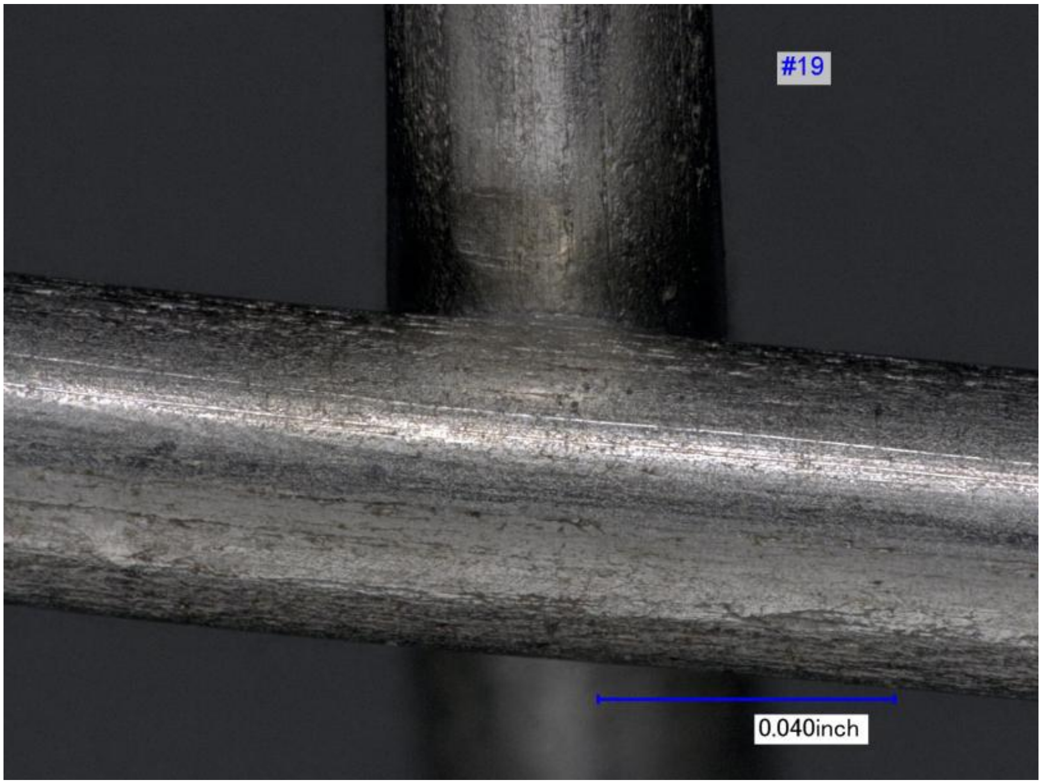
Sample #19 - 1.jpg



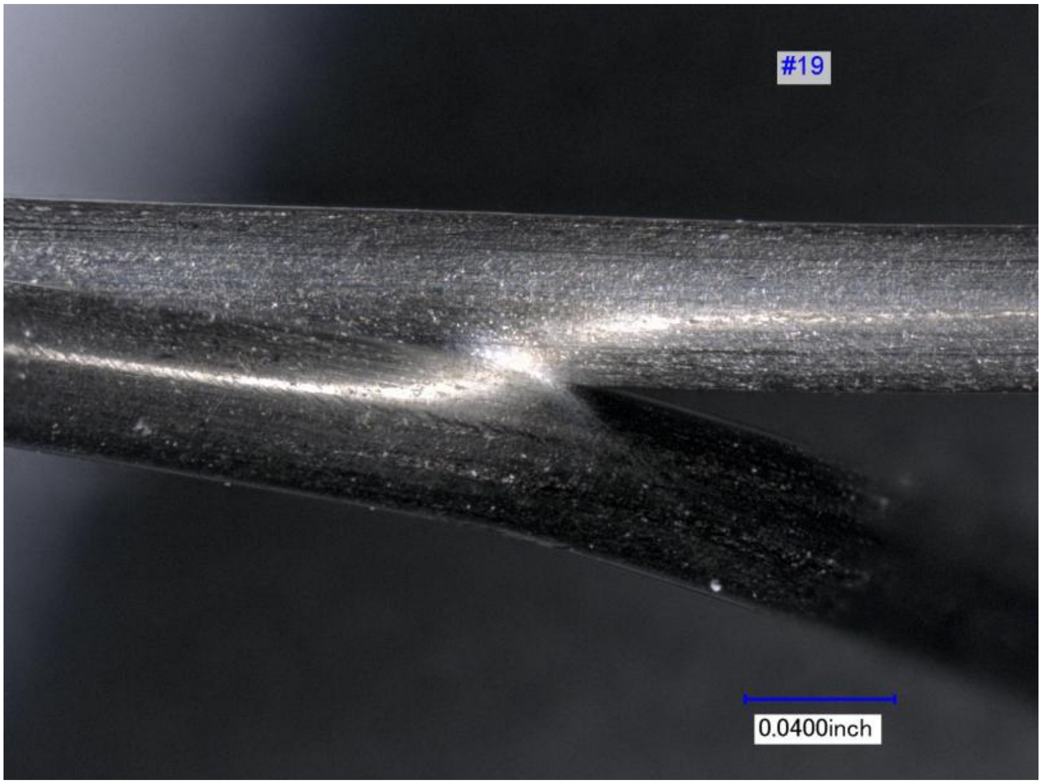
Sample #19 - 2.jpg



Sample #19 - 3.jpg



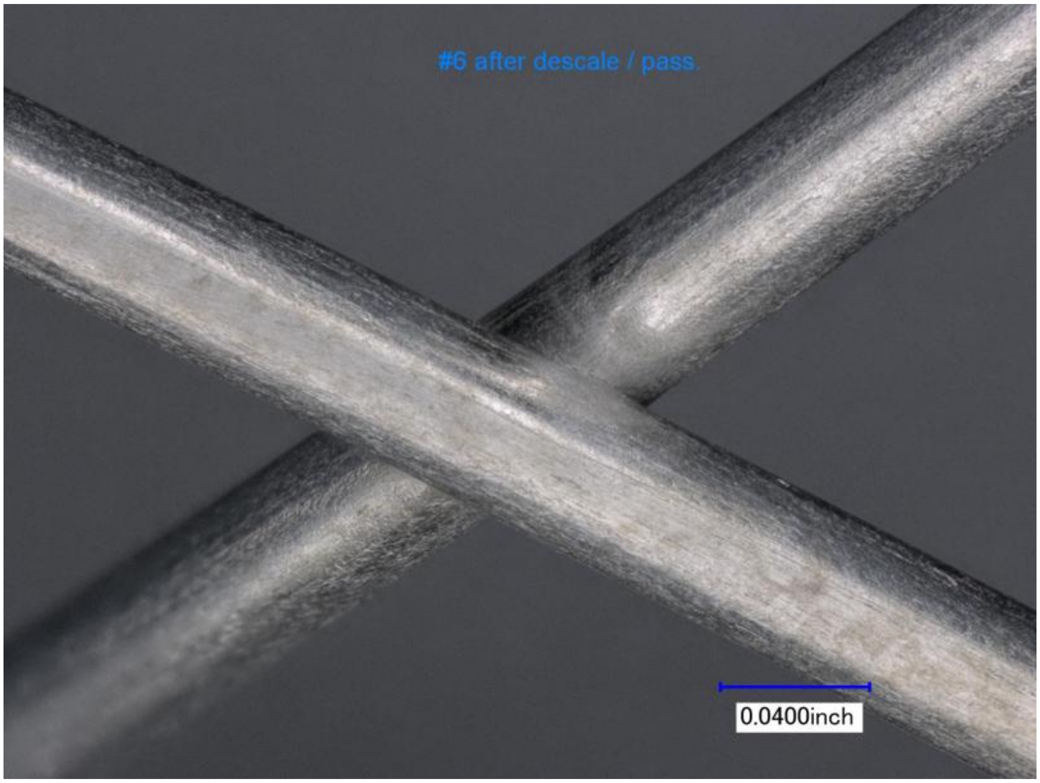
Sample #19 - 3b.jpg



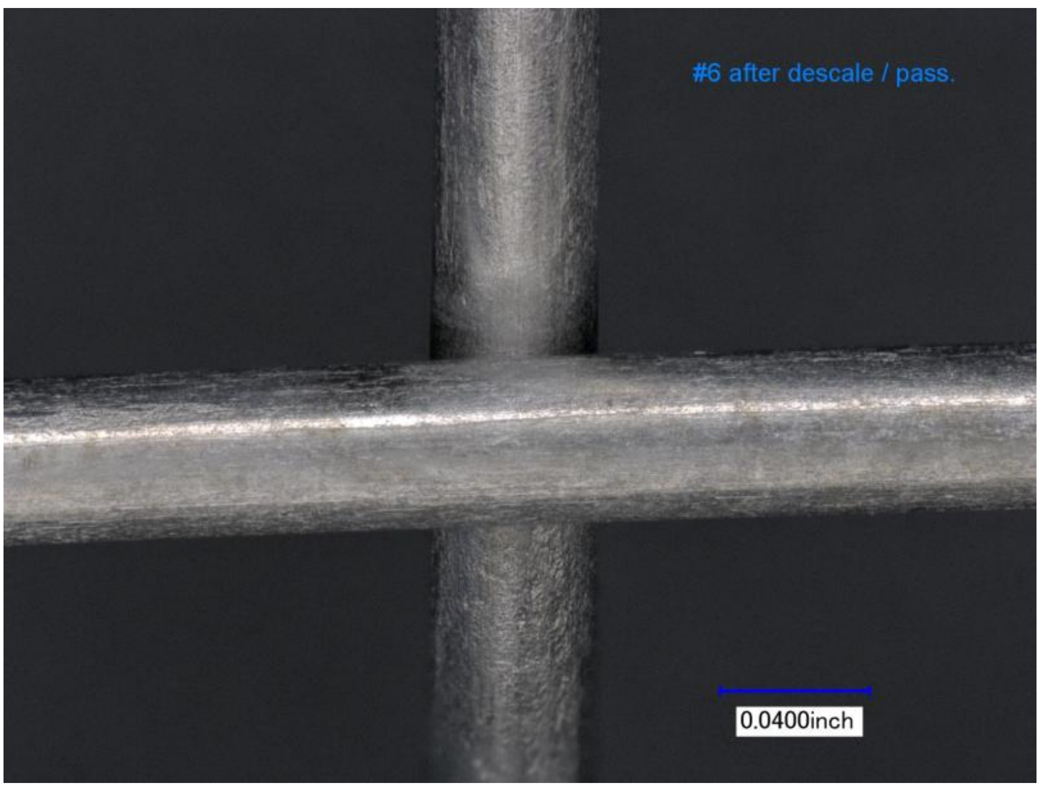
Sample #19 - 4.jpg

Welded Solid Wires After Descale & Passivation Process

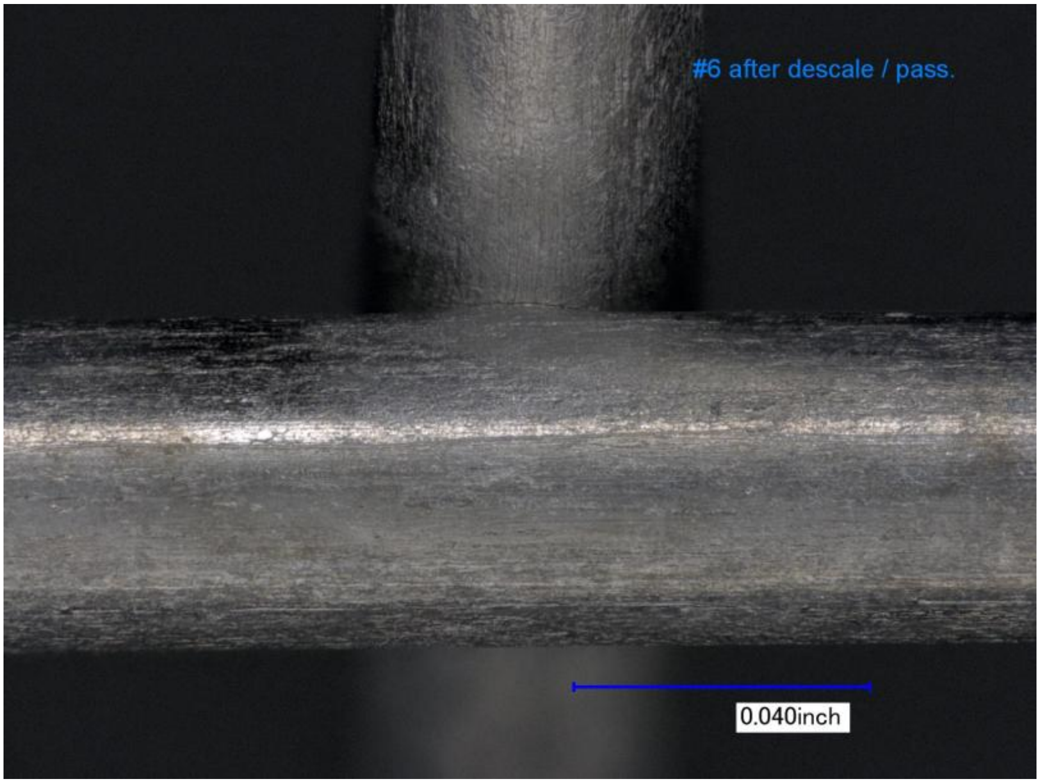
Samples #6, #7 Type 316L
Samples #13, #14 Type 317L
Samples #20, #21 Type 321



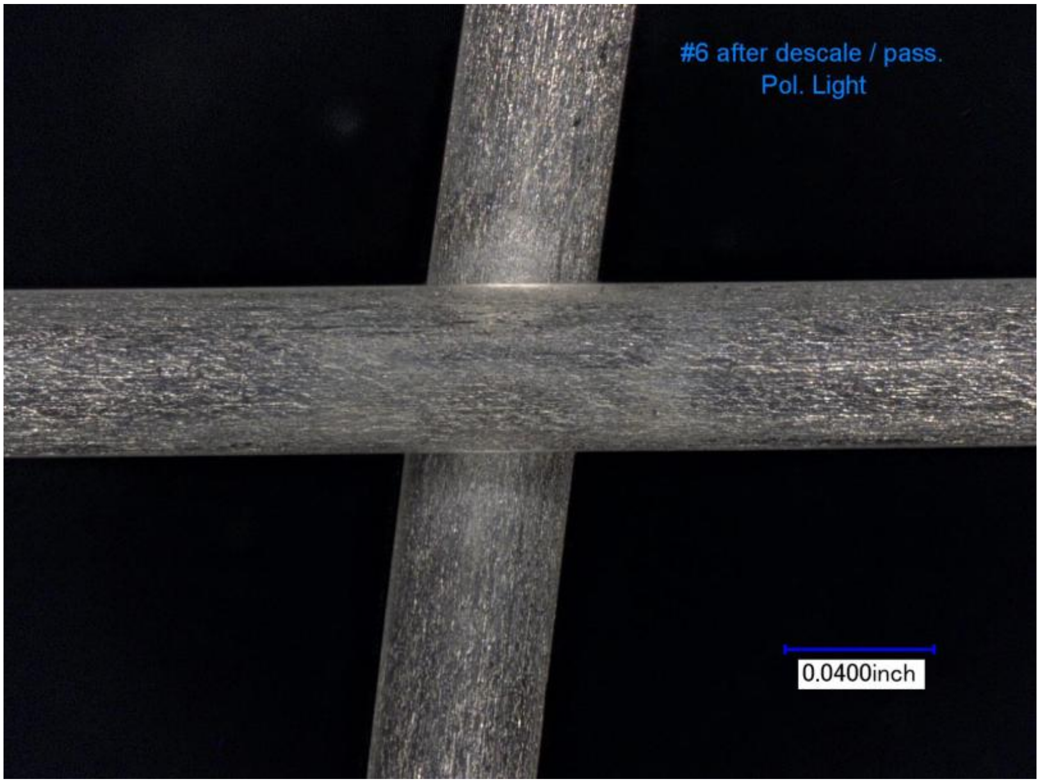
Sample #6 after descale-1.jpg



Sample #6 after descale-2.jpg

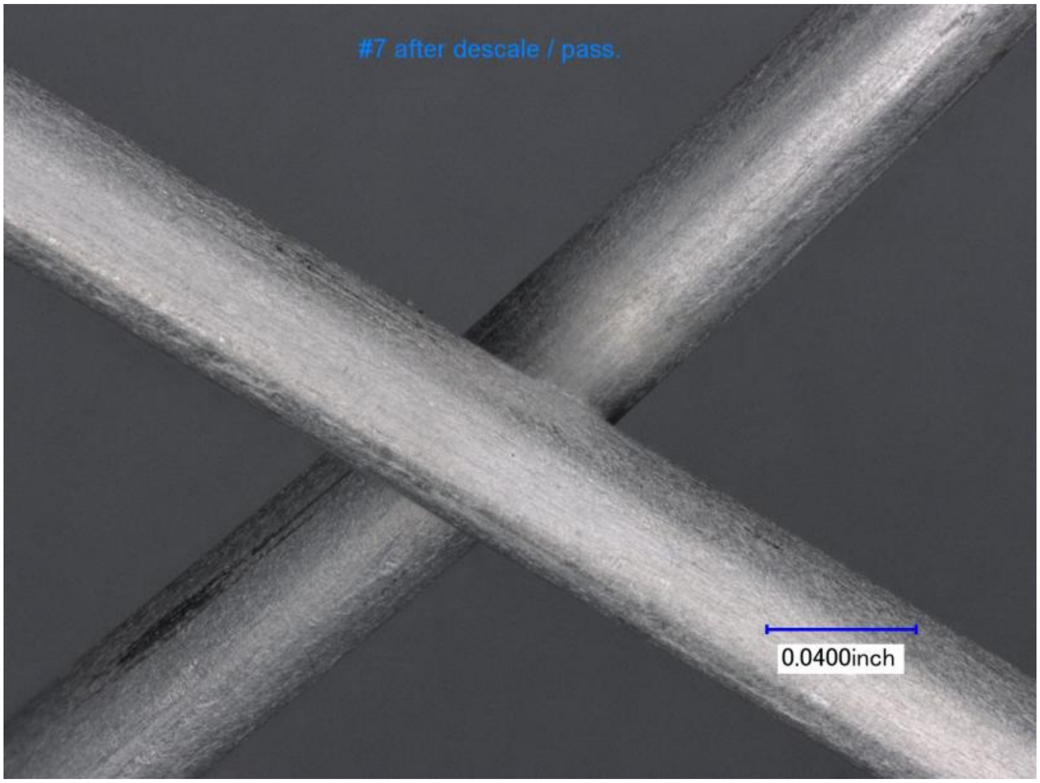


Sample #6 after descale-2b.jpg

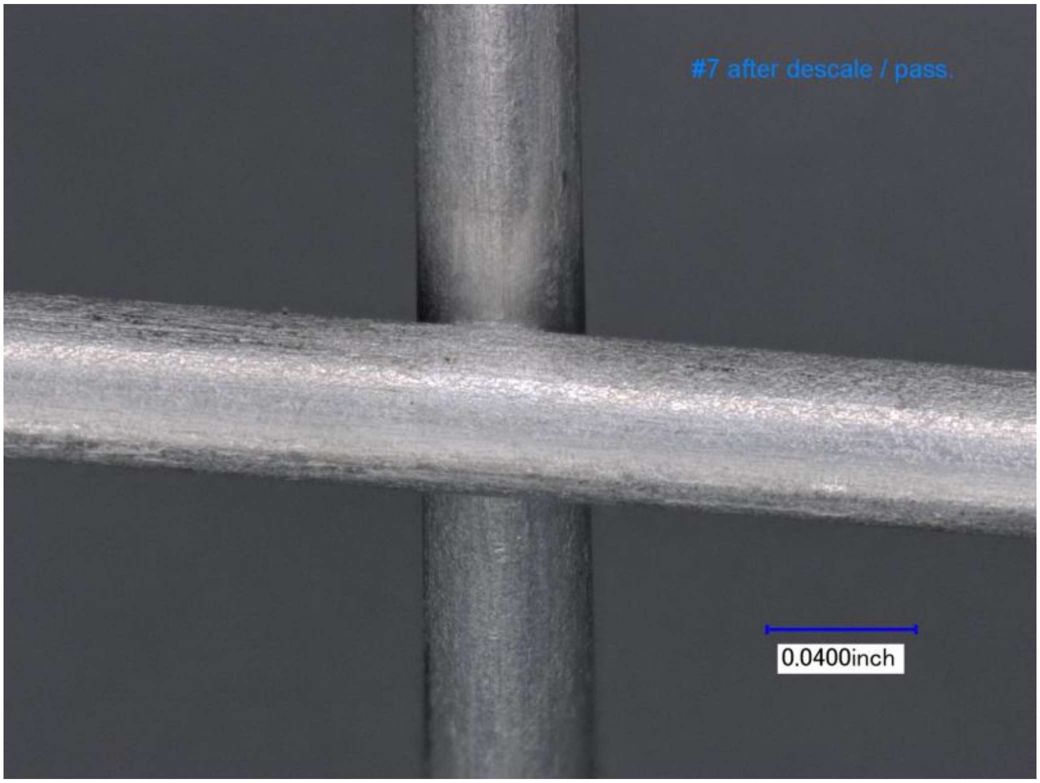


Sample #6 after descale-3.jpg

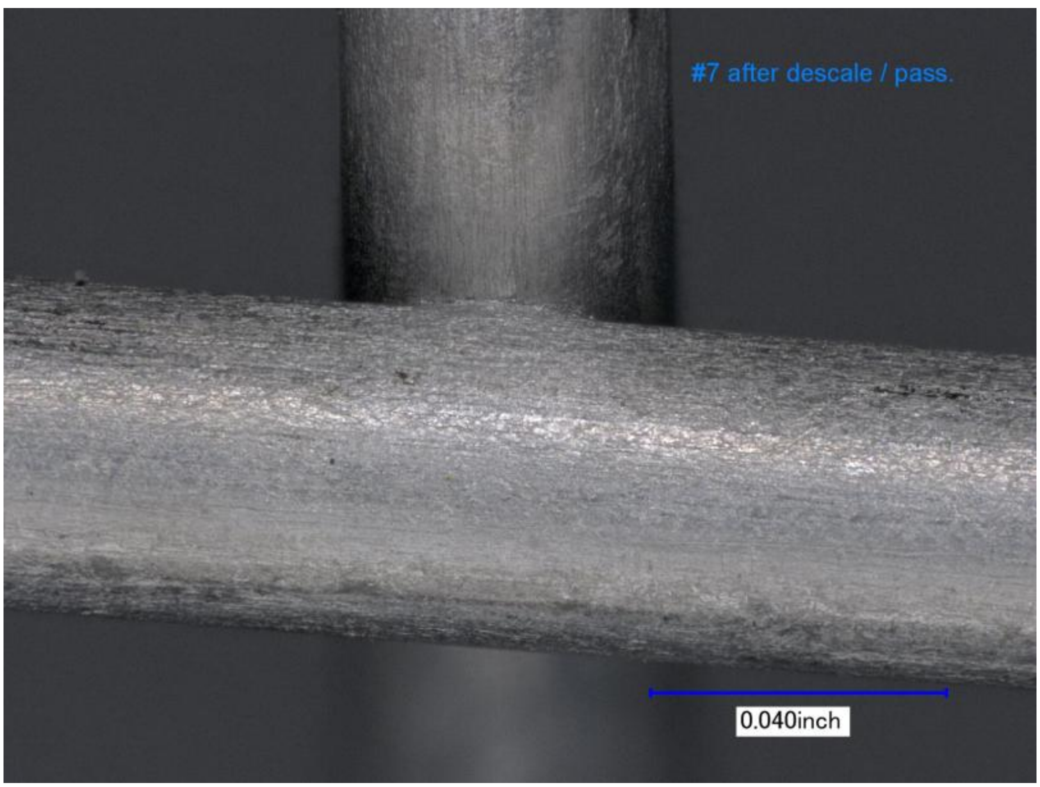
Sample #6 after descale-4.jpg



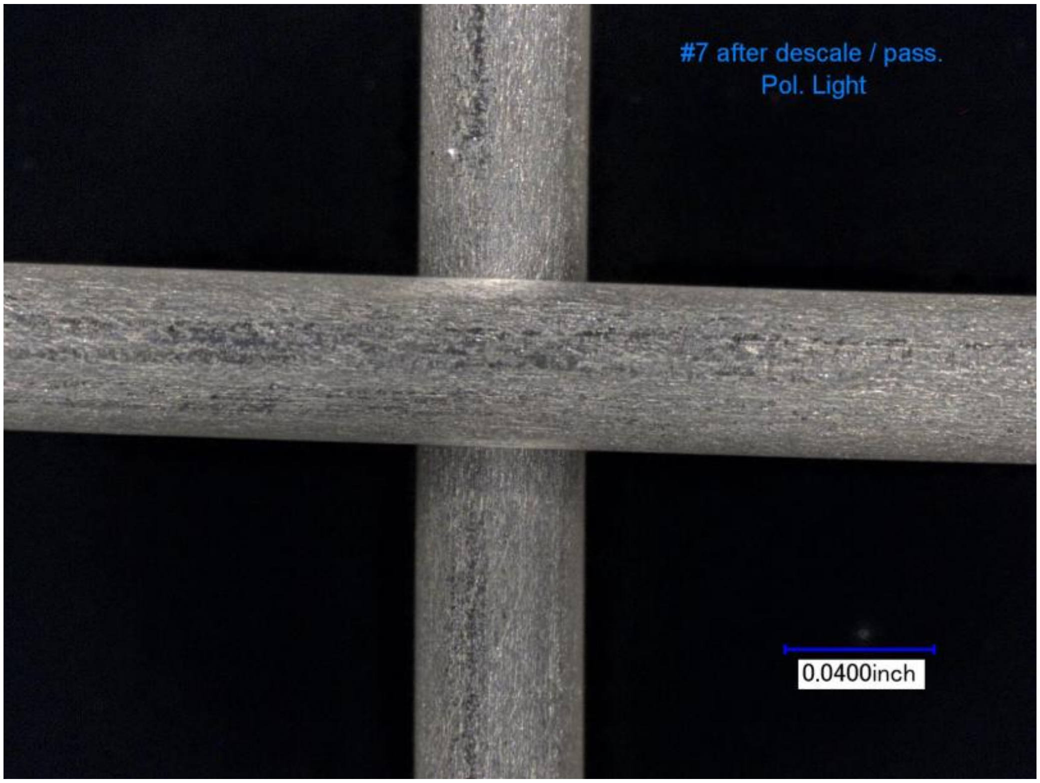
Sample #7 after descale-1.jpg



Sample #7 after descale-2.jpg

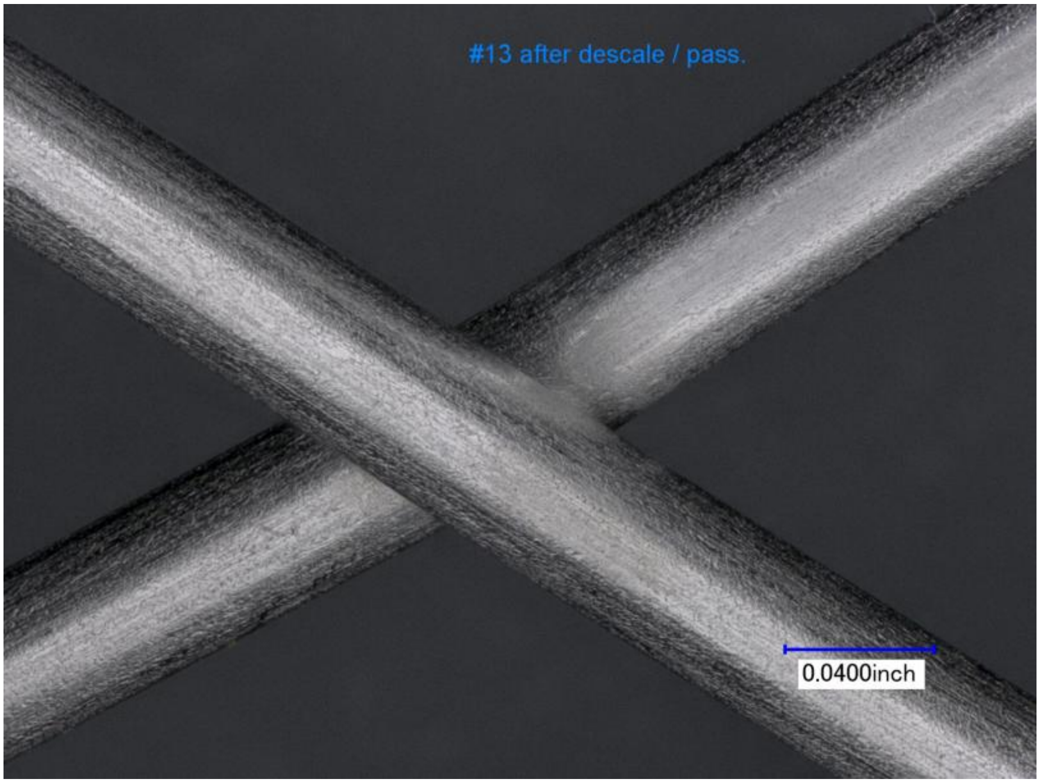


Sample #7 after descale-2b.jpg

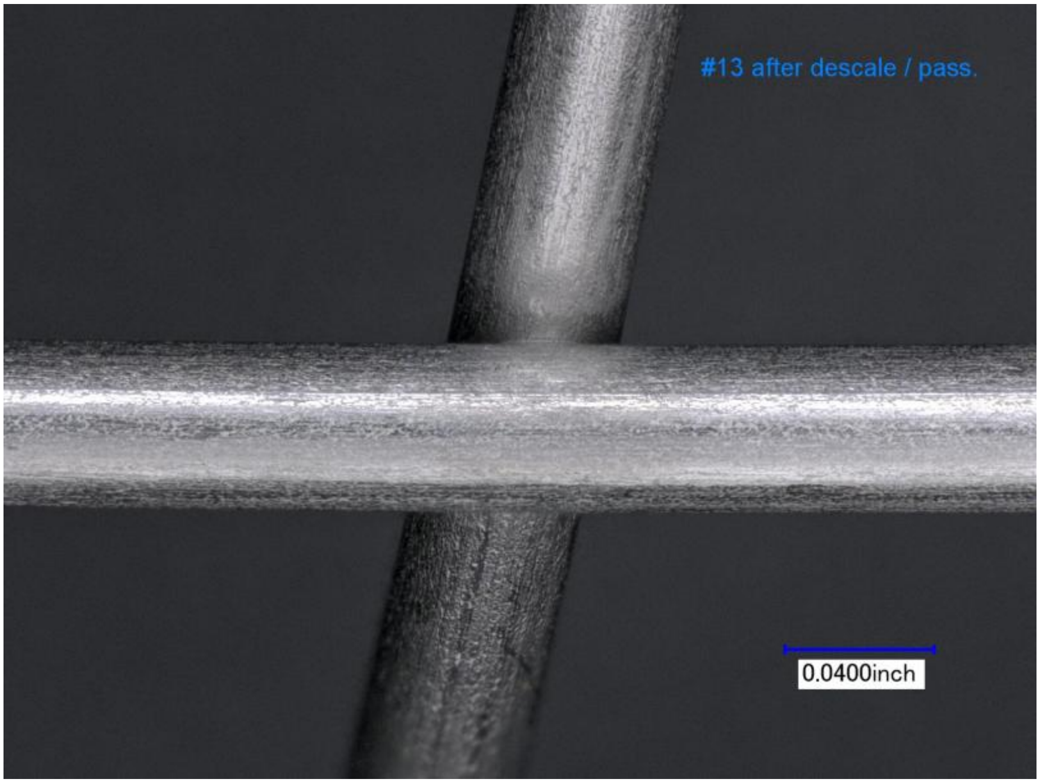


Sample #7 after descale-3.jpg

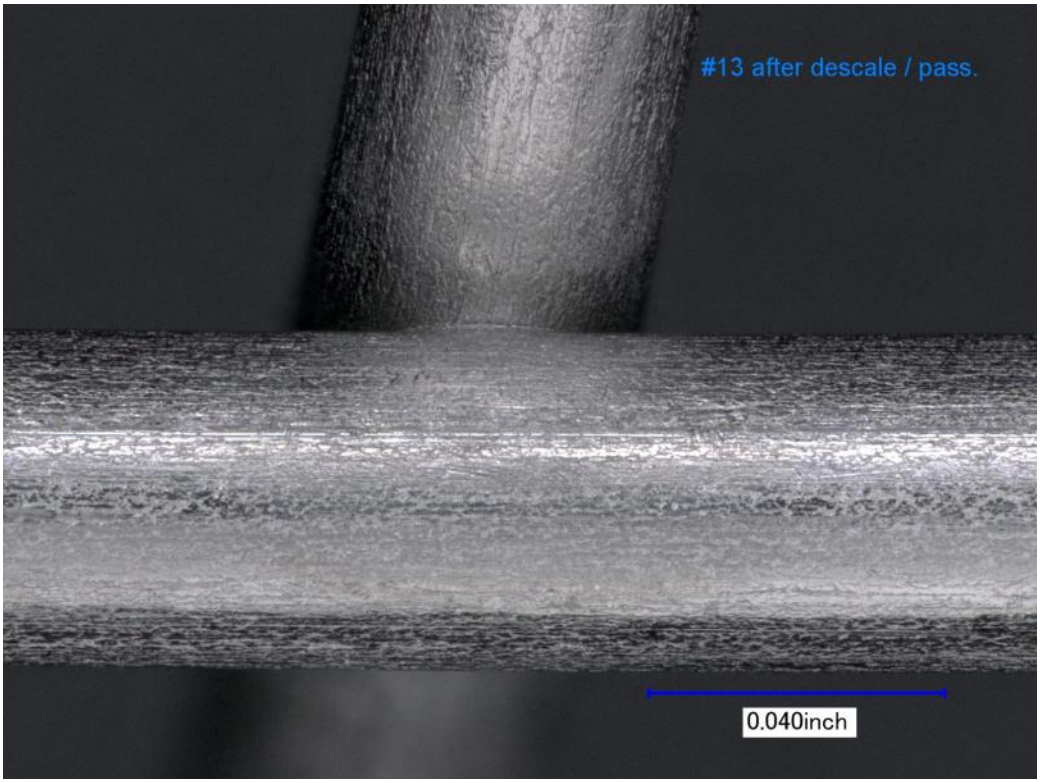
Sample #7 after descale-4.jpg



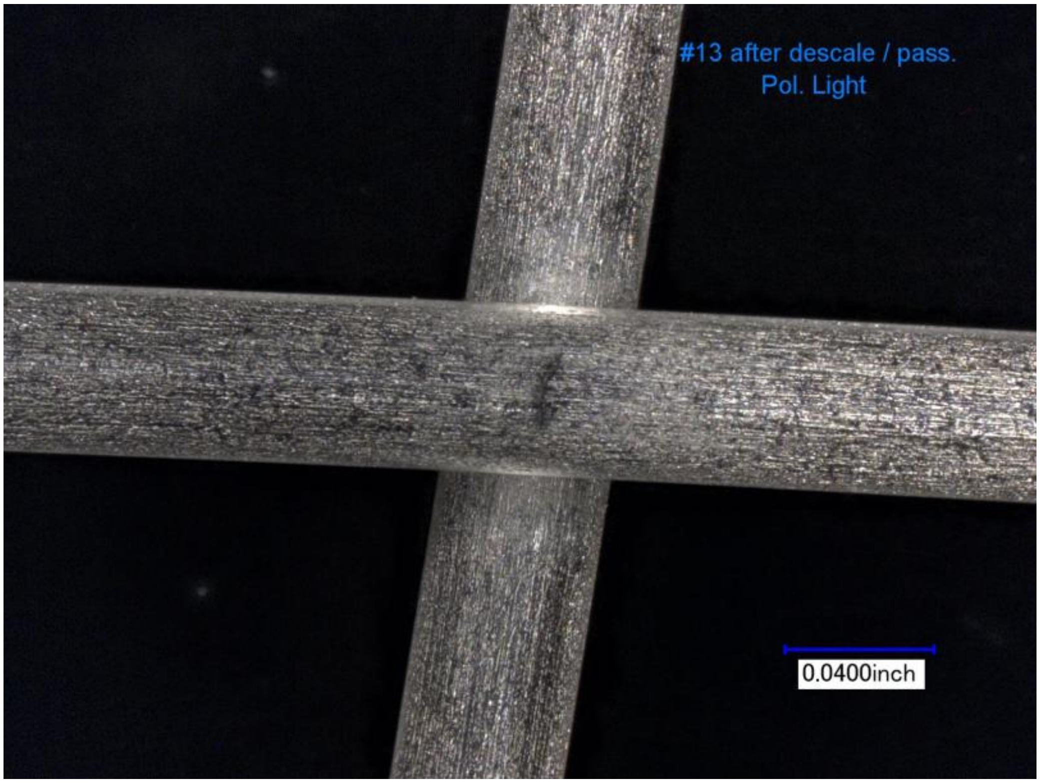
Sample #13 after descale-1.jpg



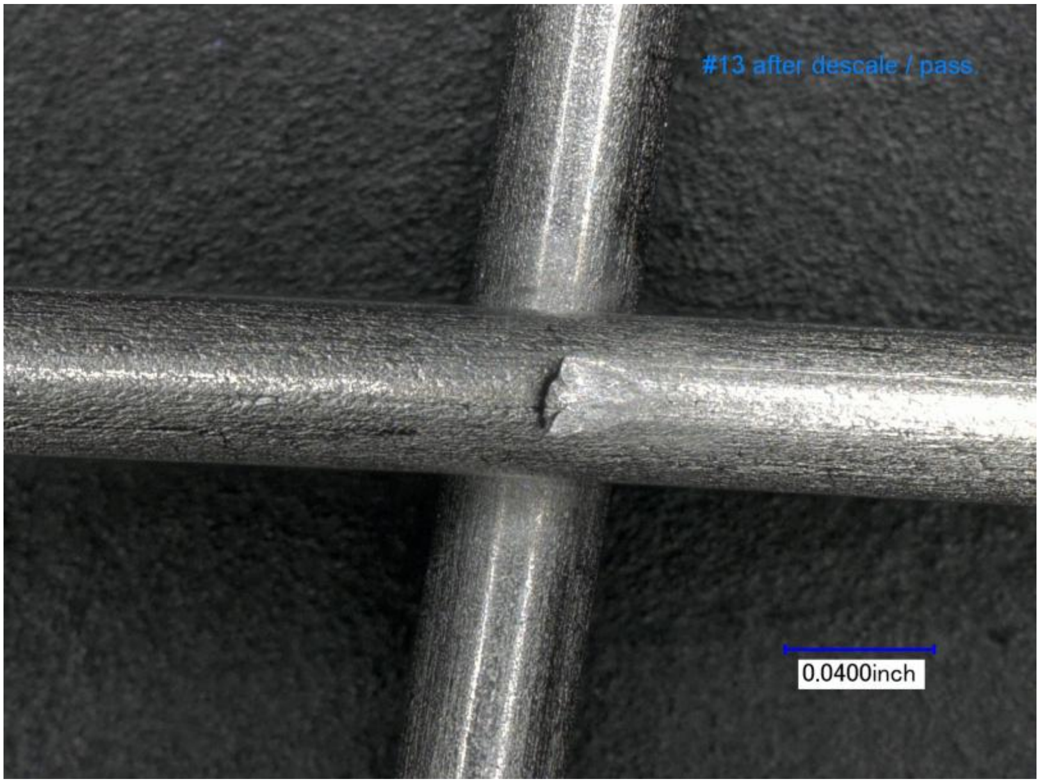
Sample #13 after descale-2.jpg



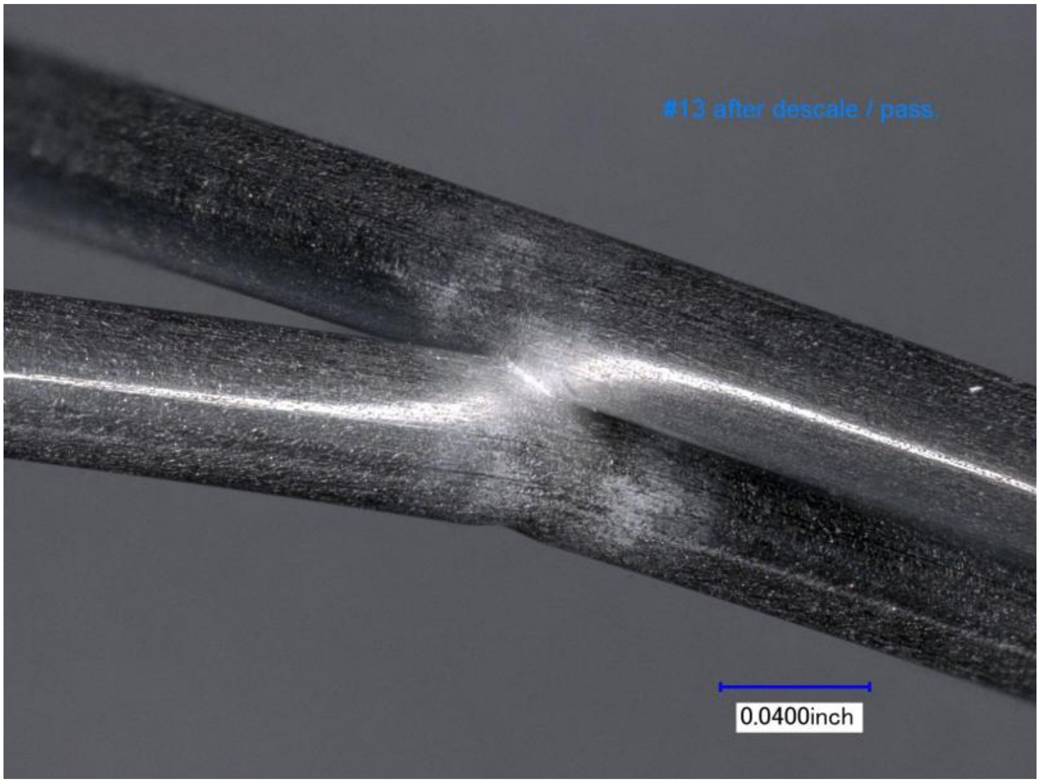
Sample #13 after descale-2b.jpg



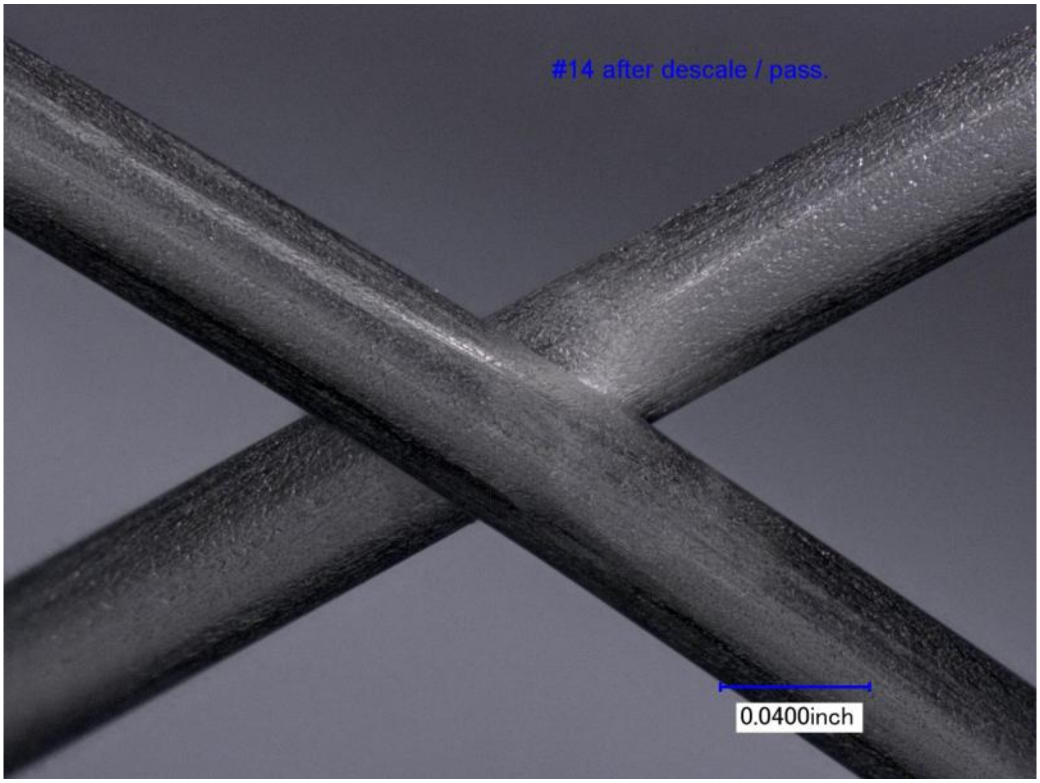
Sample #13 after descale-3.jpg



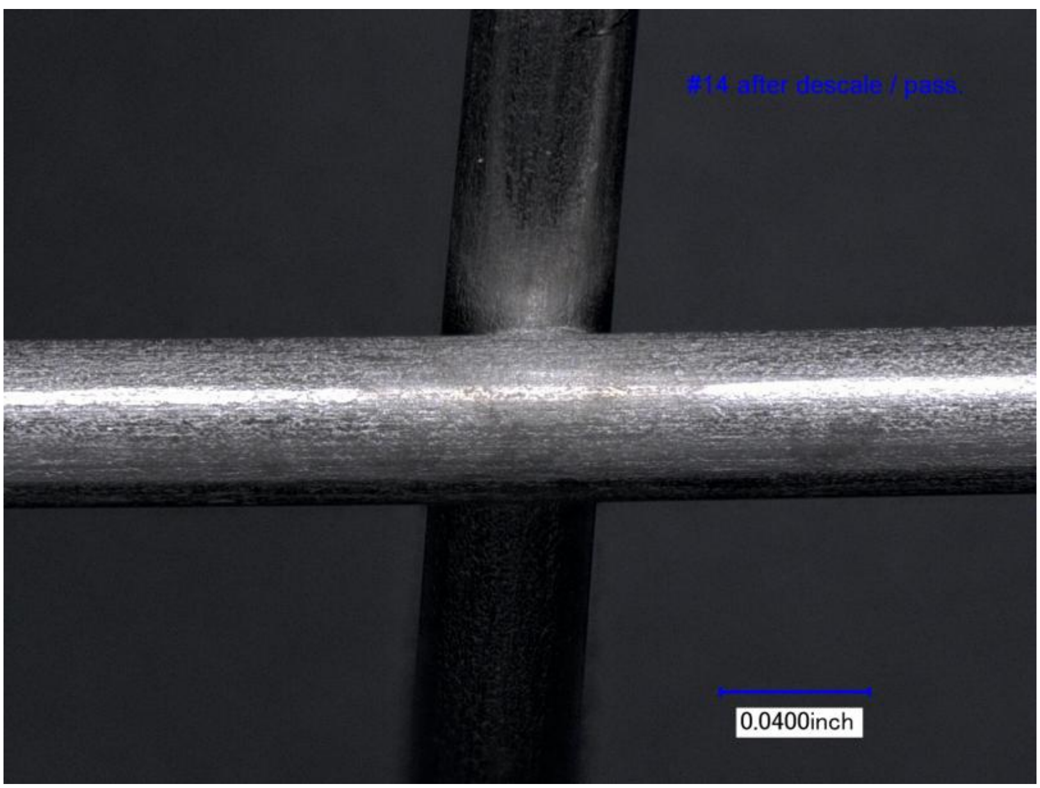
Sample #13 after descale-3b.jpg



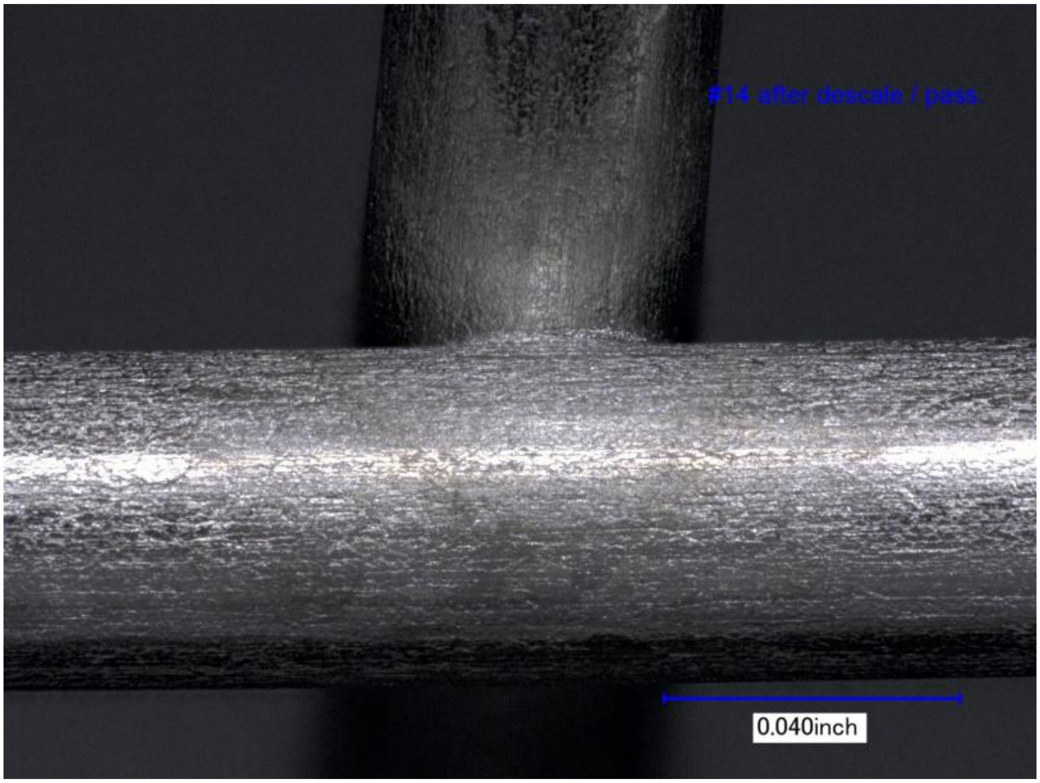
Sample #13 after descale-4.jpg



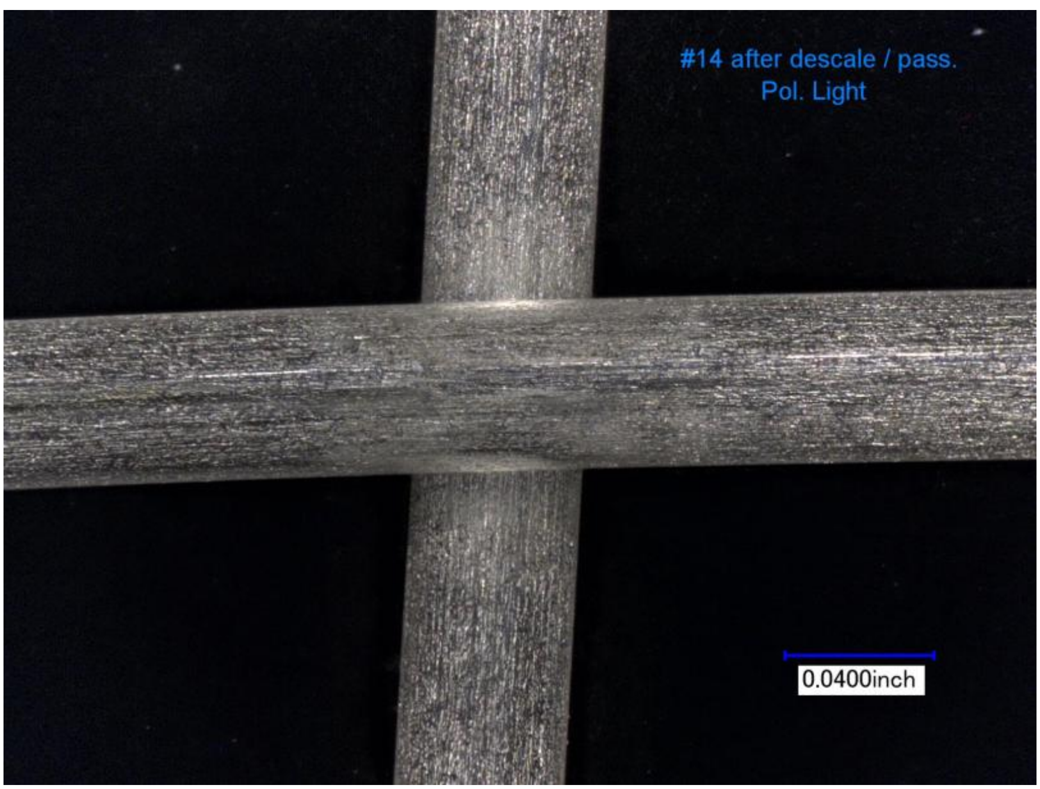
Sample #14 after descale-1.jpg



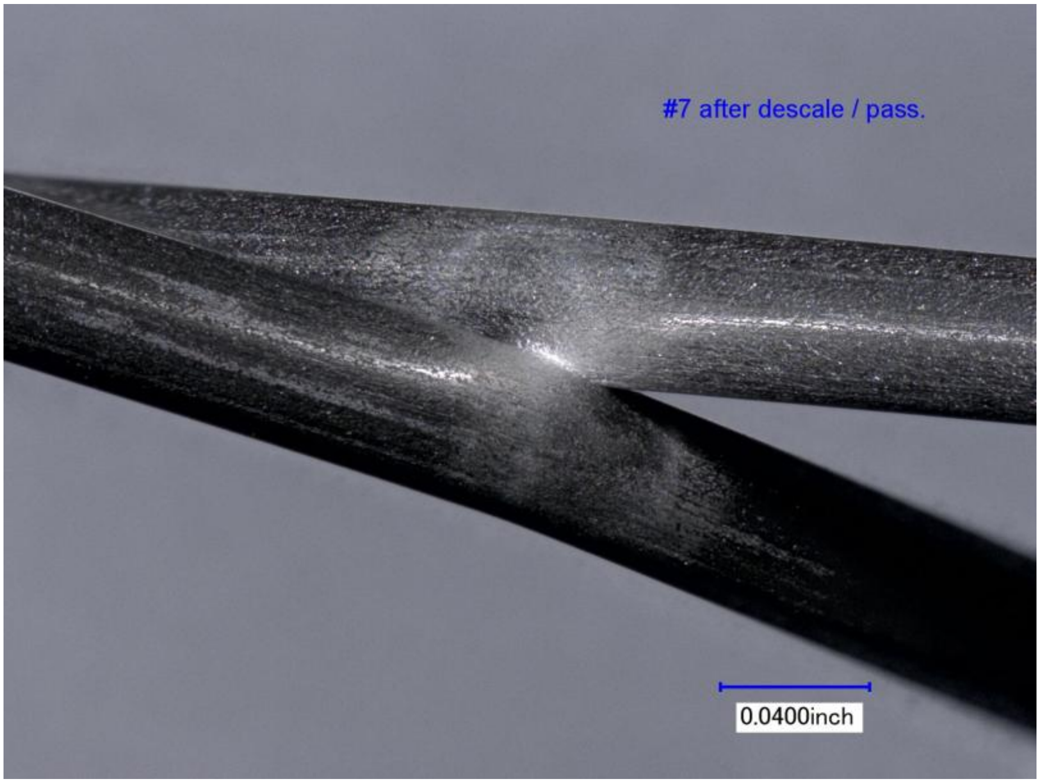
Sample #14 after descale-2.jpg



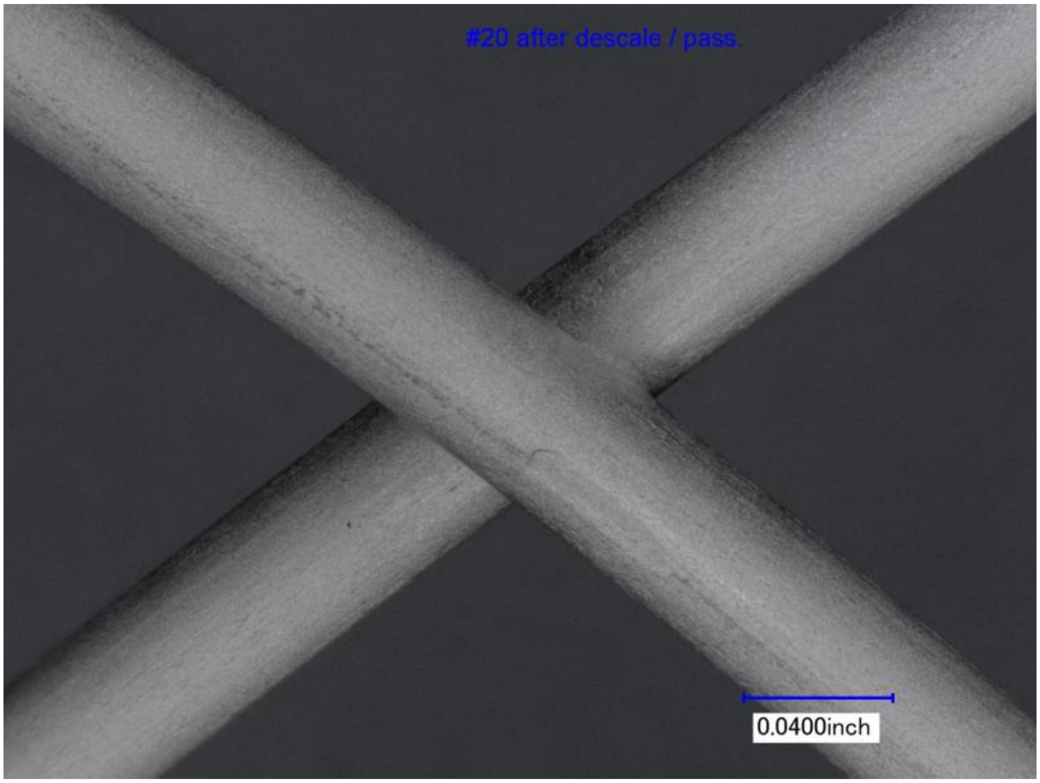
Sample #14 after descale-2b.jpg



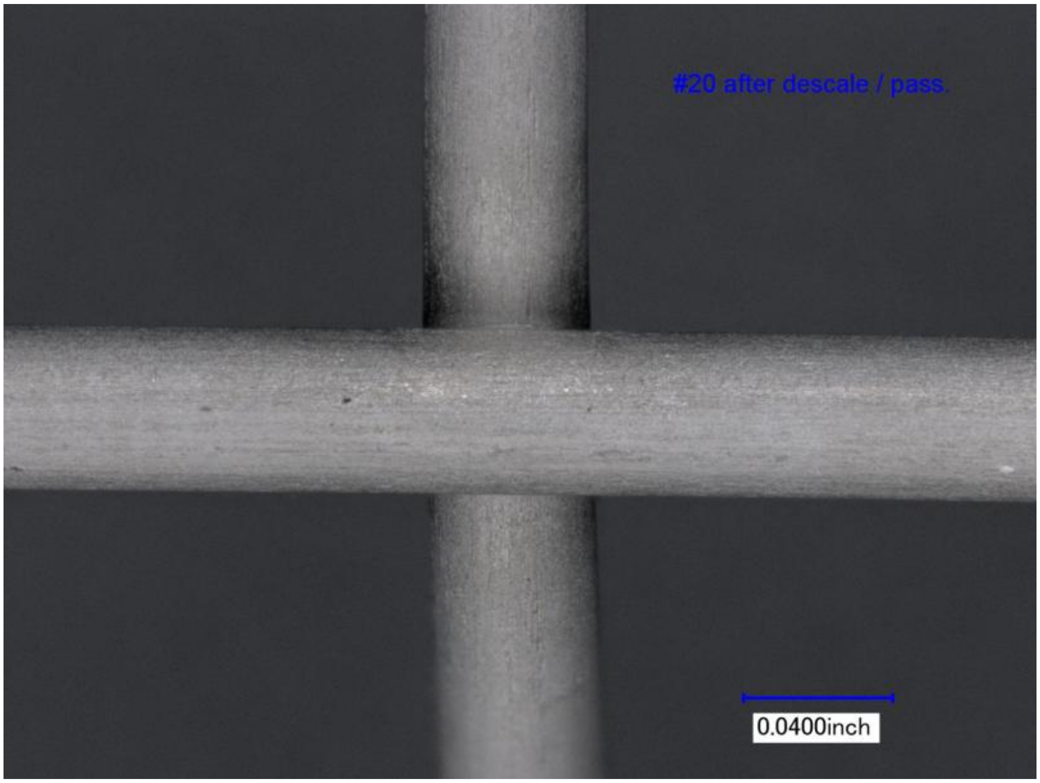
Sample #14 after descale-3.jpg



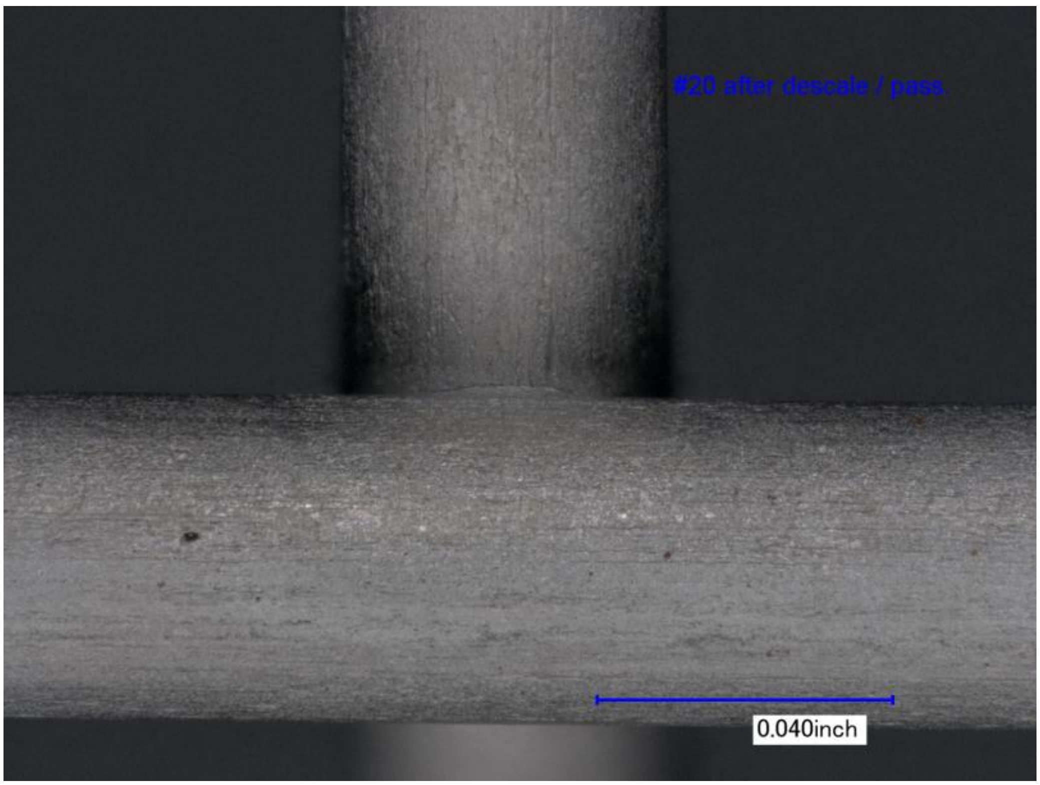
Sample #14 after descale-4b.jpg



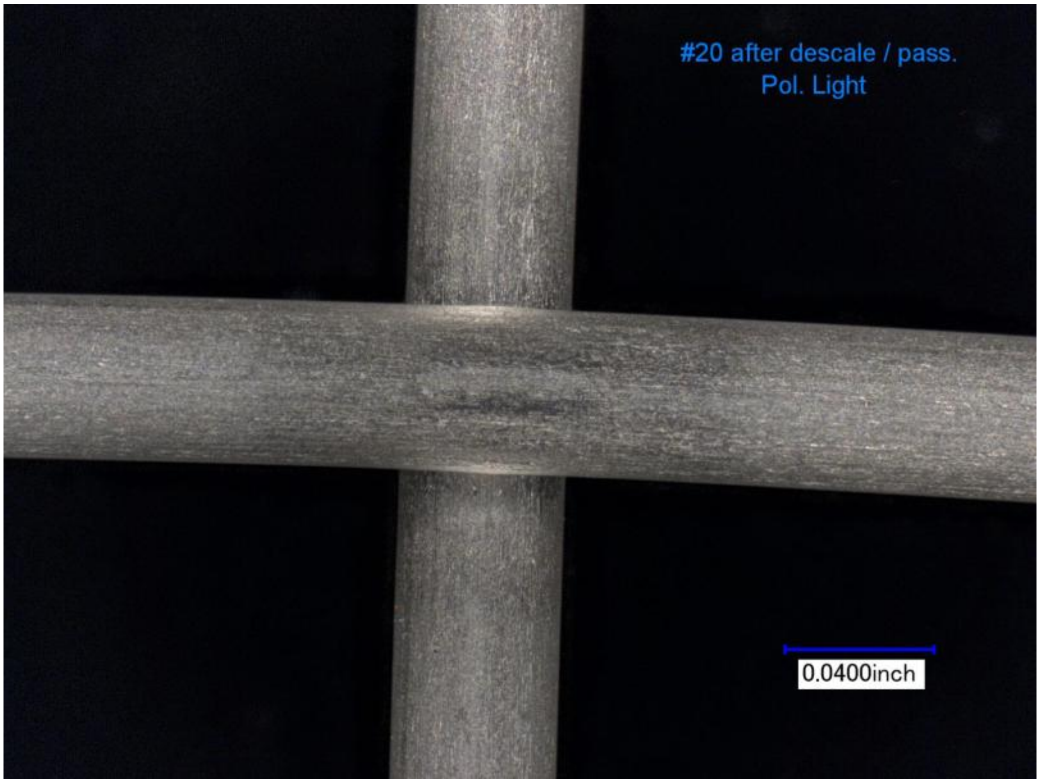
Sample #20 after descale-1.jpg



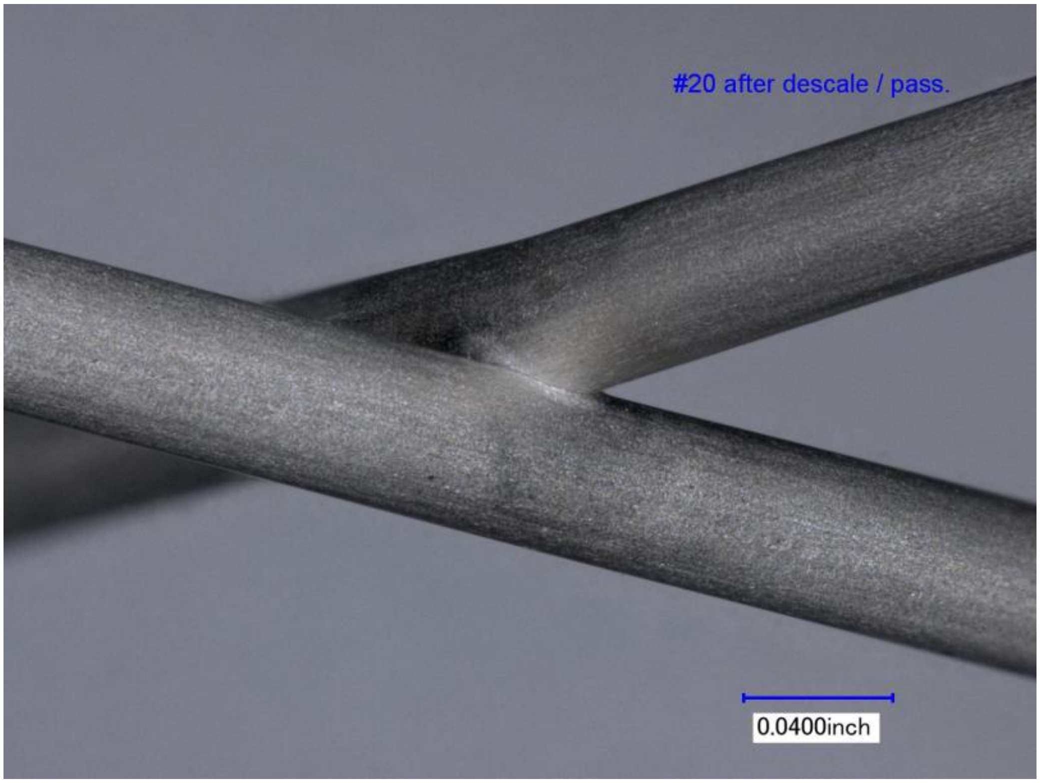
Sample #20 after descale-2.jpg



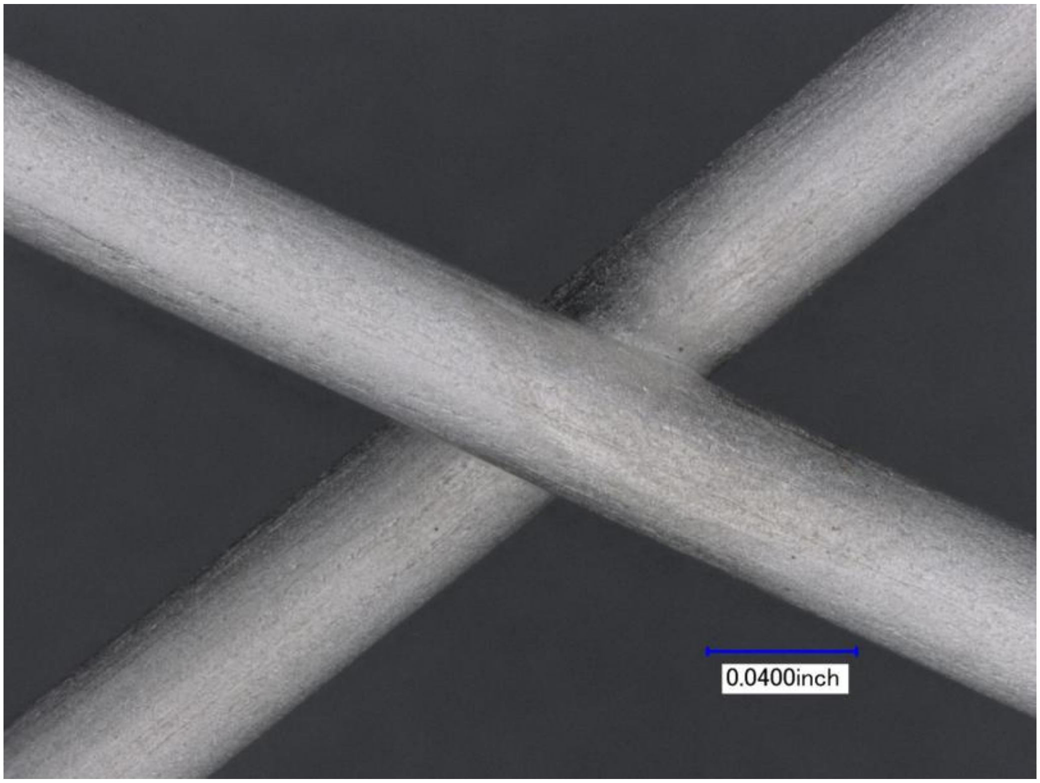
Sample #20 after descale-2b.jpg



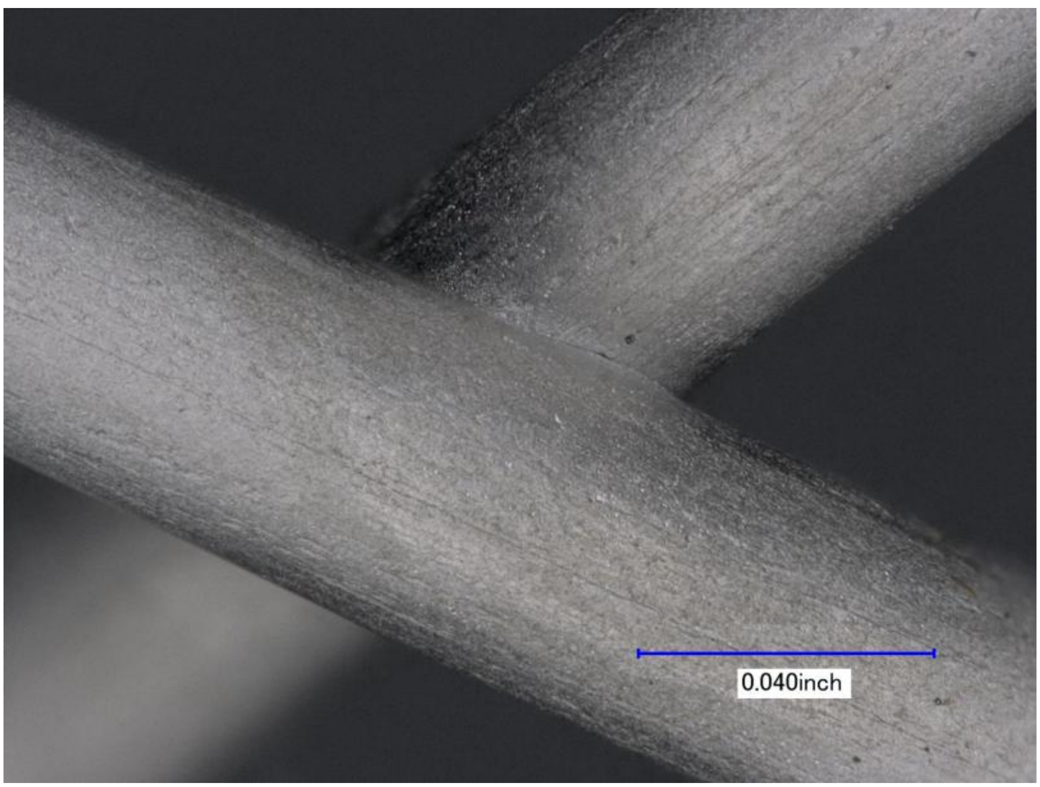
Sample #20 after descale-3.jpg



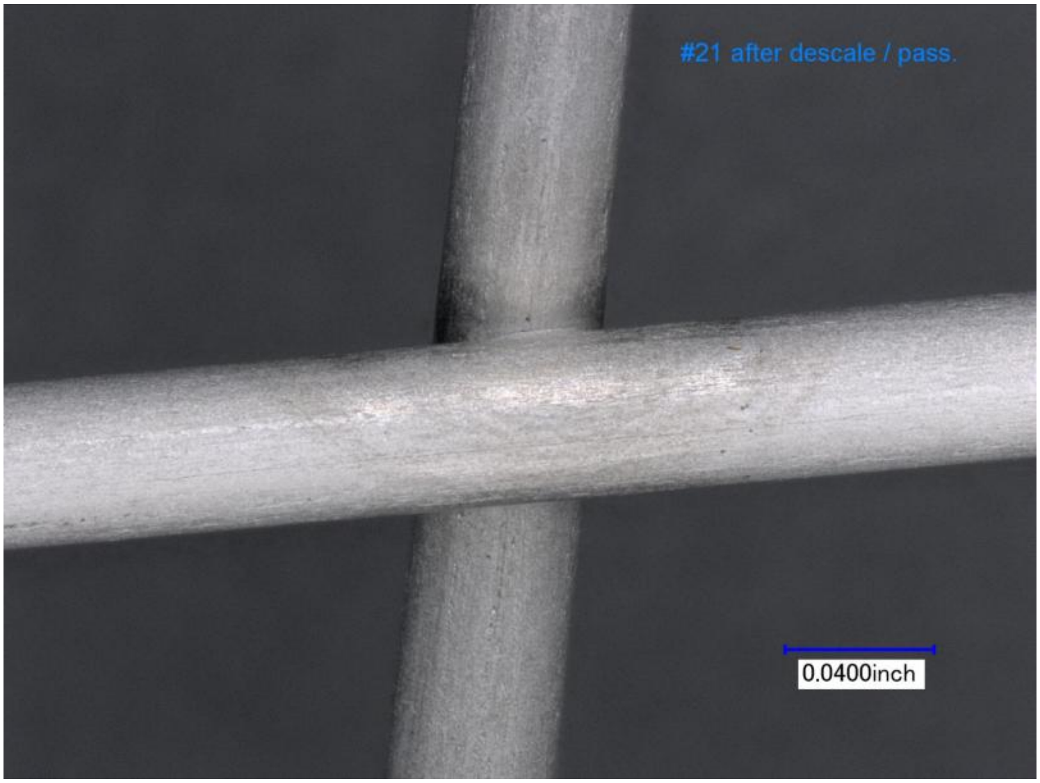
Sample #20 after descale-4.jpg



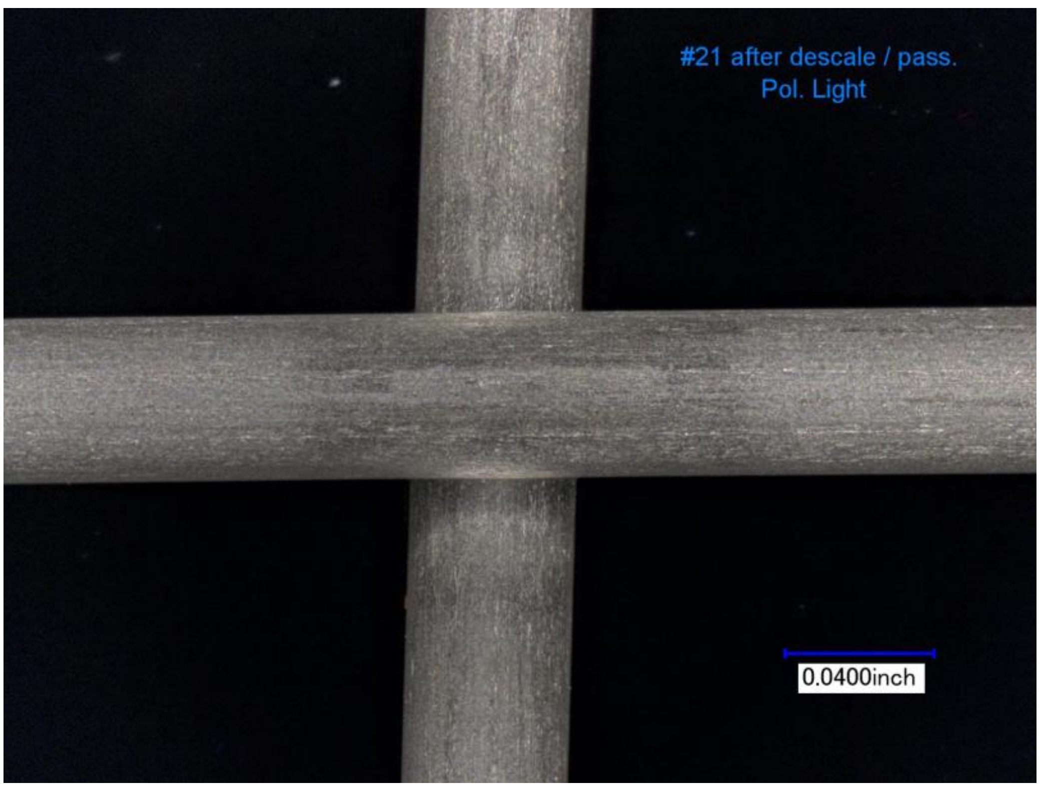
Sample #21 after descale-1.jpg



Sample #21 after descale-1b.jpg



Sample #21 after descale-2.jpg



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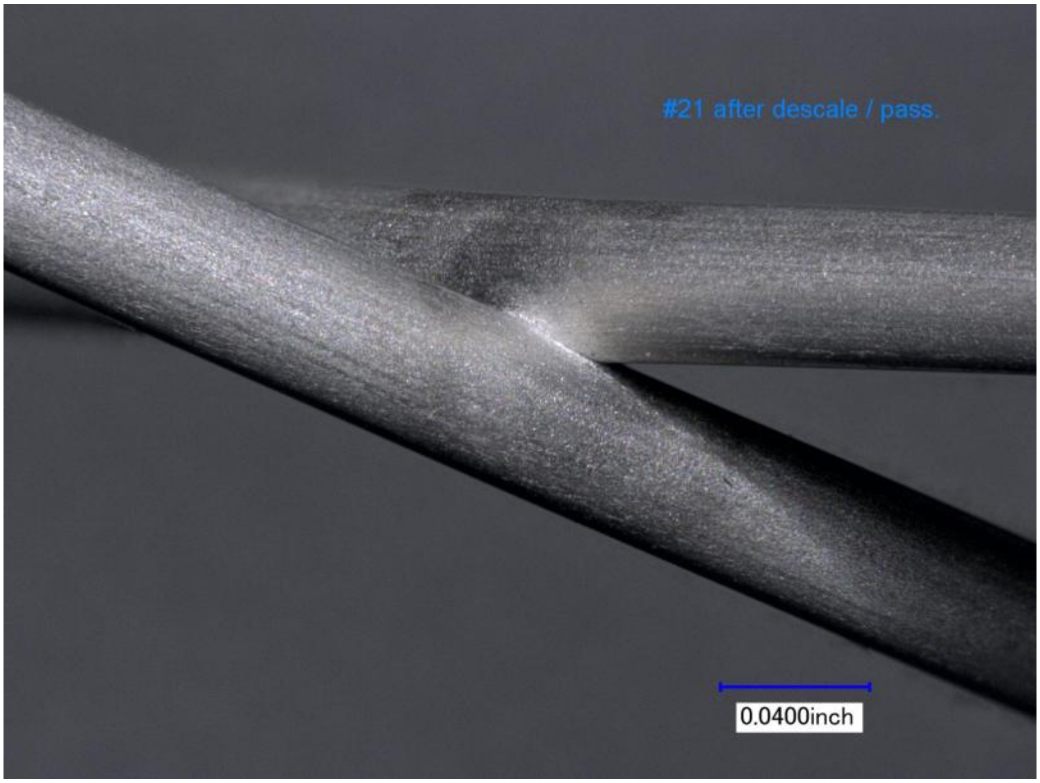

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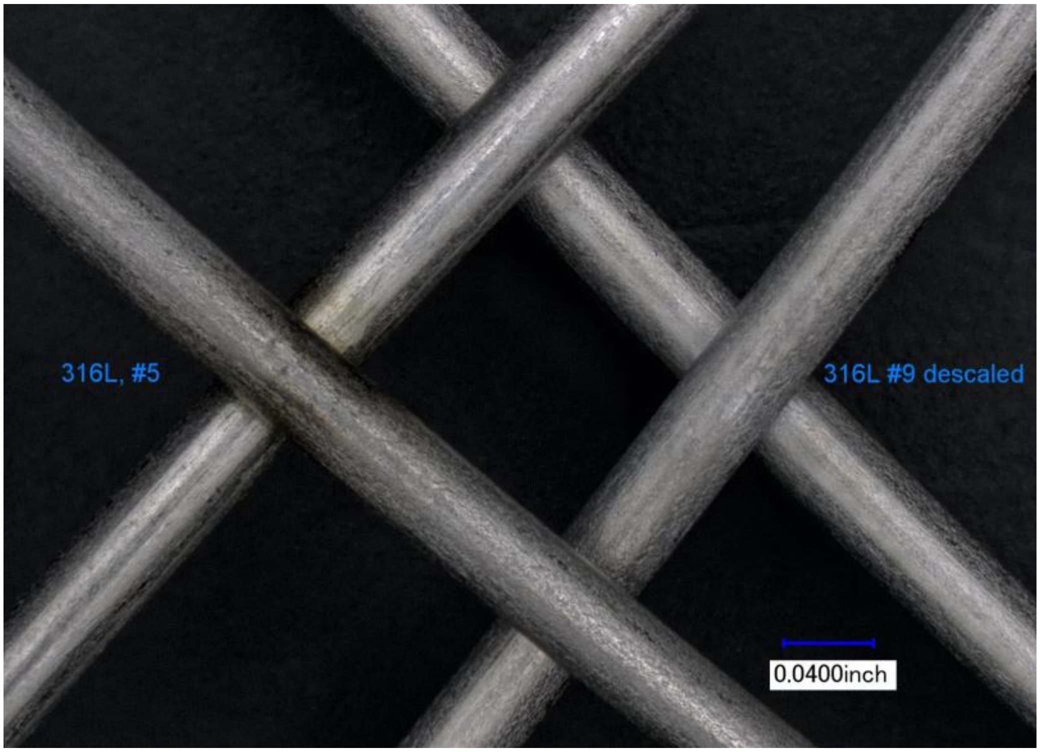
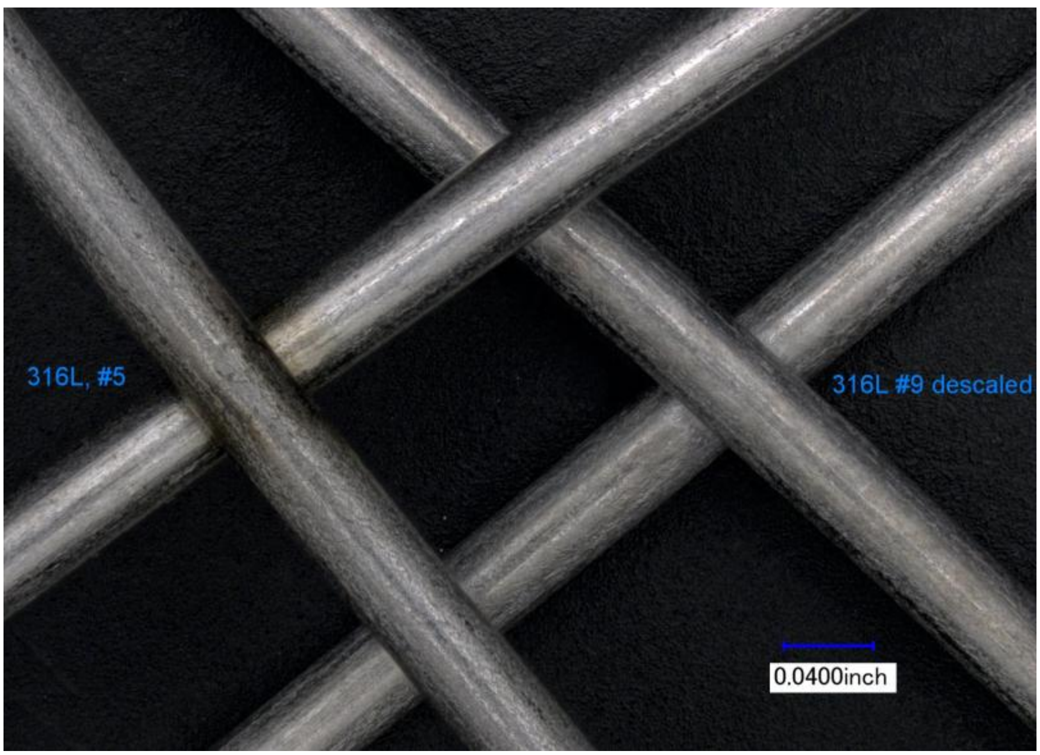
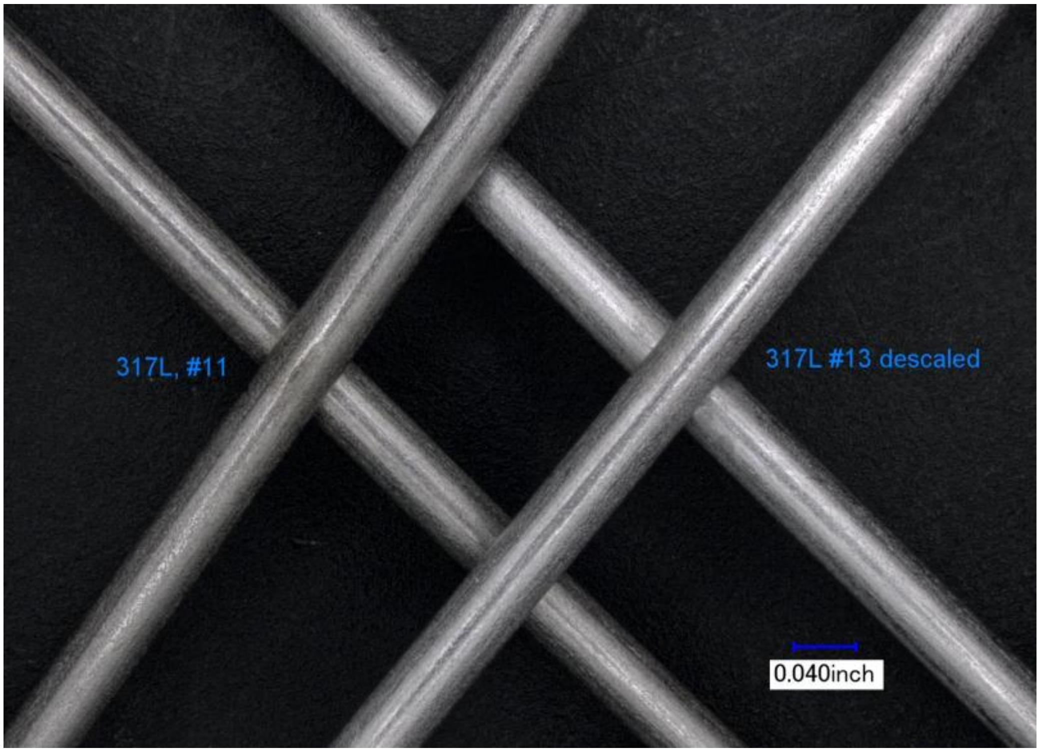


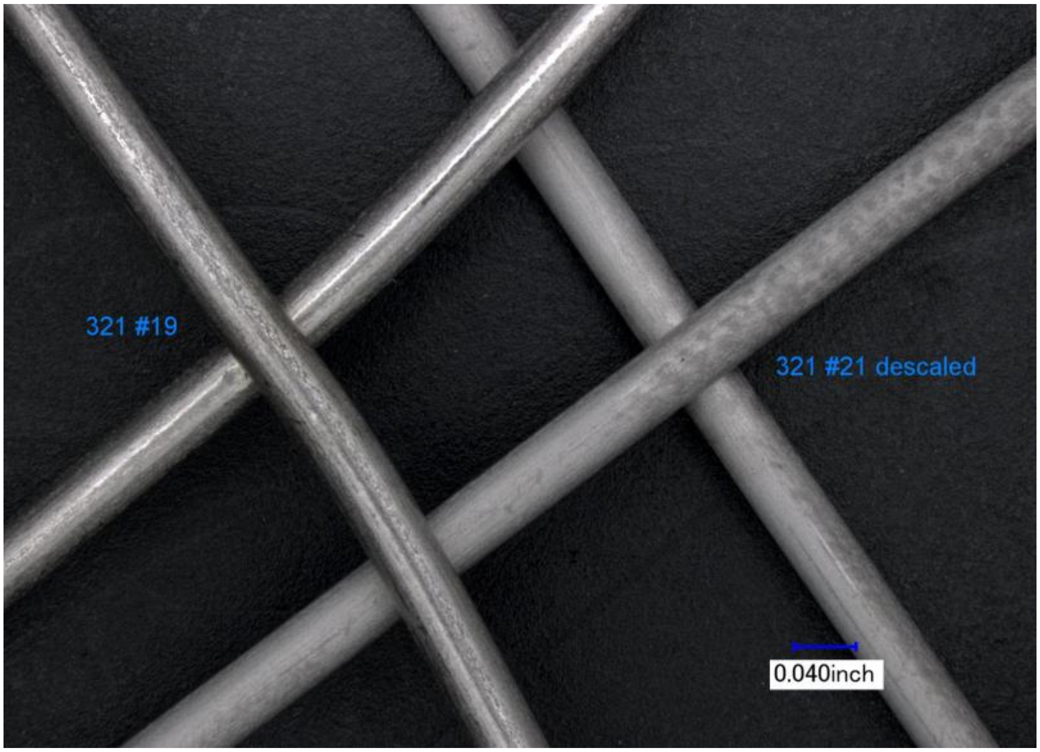
Sample #5 (as-received) and Sample #9 (after descale & passivation) shown. Type 316L



Sample #5 and Sample #9 shown photographed using slightly different lighting than in upper image.
316L Comparison - 2.jpg,



Sample #11 (as-received) and Sample #13 (after descale & passivation) shown. Type 317L



Sample # 19 (as-received) and Sample #21 (after descale & passivation) shown. Type 321

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7.5 WIND BLOWN DEBRIS TEST

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Gale Associates, Inc.
1122 Kenilworth Drive, Suite 206 | Towson, MD 21204-2143
P 443.279.4500 F 443.279.4560 www.galeassociates.com

May 15, 2012

Gilbane Building Company
2101 Constitution Avenue, NW
Washington, DC 20037

Re: Stainless Steel Tapestry Mock-up Testing for Debris
Dwight D. Eisenhower Memorial
Washington, D.C.
GALE JN 655503

Per your request and in accordance with our contract, Gale Associates, Inc. (GALE) witnessed a mock test for wind blown debris held on Monday May 7, 2012 at a warehouse facility at the Armed Forces Retirement Home in Washington DC. The purpose of the mock-up was to determine the potential for wind blown debris to become lodged in the tapestry and determine viable methods for removal of potentially embedded debris. Photographic documentation has been attached to this report to document the testing.

In attendance for the test was Tom Stokes (Gilbane), myself, and a helper.

Prior to GALE's arrival, Gilbane had embedded some material in the tapestry which consisted of some tissue paper and newspaper. Reportedly, the material was left in place for several days to become wetted and allowed to dry. Upon GALE's arrival, GALE requested that some wetted toilet paper be thrown at the tapestry.

Prior to initiating any testing, GALE provided a close inspection of the tapestry. The tapestry support system consists of stranded stainless steel wire. Larger diameter wires are spaced at 3 to 4-feet on center vertically with slightly smaller diameter wire spaced at 12 to 16-inches horizontally. The pattern is comprised of a combination of flat and round braided stainless steel wire woven to vertical wire strands spaced at 1-1/2 to 2-inches on center. The attachment of the braided pattern is accomplished through small welds.

GALE noticed some fraying of the strands at various locations. GALE suspected these frays of possibly catching and holding debris. Some minor discoloration of the stainless steel wire was noted at weld locations.

Gilbane utilized a leaf blower to simulate a wind event and blow plastic bags, newspaper, tissues, and miscellaneous paper products against the tapestry (see Photo 4). The materials in general did not embed into the tapestry. Only the plastic bags attached themselves, albeit loosely, to the tapestry. The leaf blower was easily able to remove the plastic bags by blowing the tapestry from the reverse direction. Plastic bags were manually embedded into the tapestry to see if the leaf blower could remove them. The pressure washer was required to remove them (see Photos 5 and 6).

Following this test, the leaf blower was used to try and remove the embedded, wet, toilet paper. The leaf blower was unsuccessful in removing the material. Gilbane was able to easily remove the embedded toilet paper with a pressure washer.

GALE recommended that the toilet paper balls be allowed to completely dry. Once they are allowed to dry, Gilbane should attempt removal with the pressure washer to ensure they are easily removed.

In conclusion, based on the testing performed today, the probability of random debris becoming lodged in the tapestry is low. The fact that the tapestry will be 15 to 20-feet above grade would most likely further reduce this potential. GALE does see a concern for wetted toilet paper becoming embedded into the tapestry or toilet paper balls being thrown into the tapestry from ground level. Today's testing indicated that this material must be removed using a pressure washer.

We anticipate that this report suits your needs at this time. Please do not hesitate to contact GALE if you require additional information regarding this project.

Very truly yours,
GALE ASSOCIATES, INC.

Steven J. Bohlen, P.E., RRC
Building Technology Division

Attachment:

- Photographic Documentation (5 pages)

PHOTOGRAPHIC DOCUMENTATION

Photo 1: Overall view of tapestry prior to windblown debris testing.

Photo 2: Overall view of tapestry prior to windblown debris testing.

PHOTOGRAPHIC DOCUMENTATION

Photo 3: Overall view of tapestry prior to windblown debris testing.

Photo 4: Debris being introduced to the tapestry.

PHOTOGRAPHIC DOCUMENTATION

Photo 5: Debris being removed from tapestry. Removal with air was not completely successful.

Photo 6: Debris in Photo #5 was removed with high pressure water.

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7.6 STAINLESS STEEL AND WELD INFORMATION REFERENCE DOCUMENTS

Included in this section:

- U.S. Airforce Memorial - “Stainless Steel Soars to New Heights” - Welding Journal, May 2007
- Korean War Memorial - Electralloy News Post, May 26, 2009
- Fundamentals of Small Parts Resistance Welding January 2013 - Miyachi Unitek
- Resistance Welding “Tech Tips” - Murray Corporation
- “Fabricating Railcars with Resistance Welding” - Welding Journal, December 2010

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Stainless Steel Welding Soars to New Heights

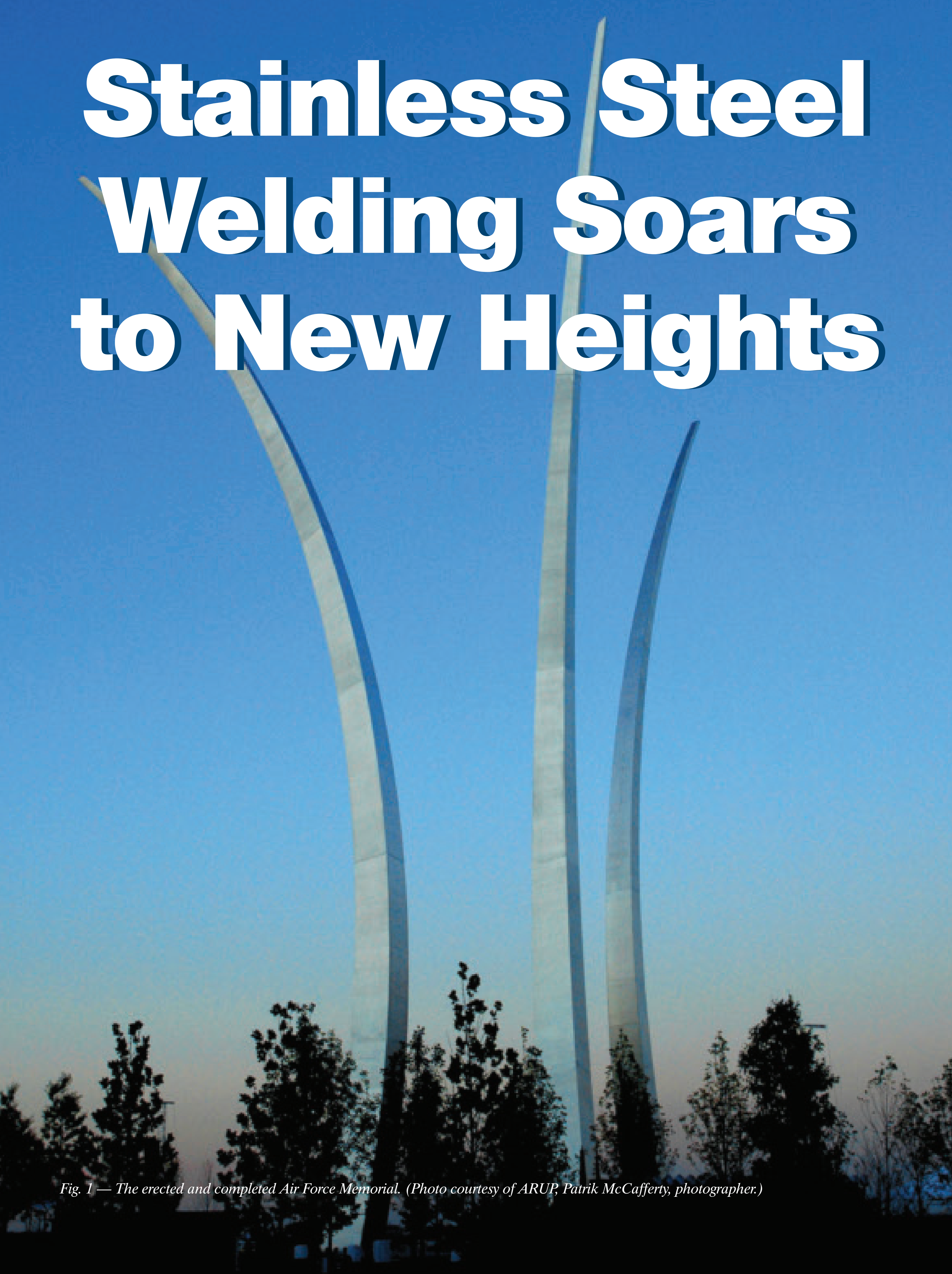

Fig. 1 — The erected and completed Air Force Memorial. (Photo courtesy of ARUP, Patrik McCafferty, photographer.)

High-quality stainless steel welds were critical to achieving the designer's long-term structural integrity and aesthetic goals

BY RON STAHURA AND CATHERINE HOUSKA

Gracefully curving, triangular, Type 316L stainless steel spires form the centerpiece of the new United States Air Force Memorial, which was dedicated in October 2006. Rising from a hill in Arlington National Cemetery and overlooking the Pentagon, the Air Force Memorial's three spires are a highly visible addition to the Washington skyline. This spectacular memorial honors the men and women of the U.S. Air Force and its heritage organizations while symbolizing its three core values — integrity, service, and excellence — and its total force, which encompasses the active duty, reserve, and guard forces. Its shape emulates the "bomb-burst" flying formation made famous by the Thunderbirds — Fig. 1.

High-quality welds were a critical aspect of achieving the designer's long-term structural integrity and aesthetic goals. Innovative weld fixturing (Fig. 2) and careful attention to joint detailing, specification, welding, and inspection were necessary to bring this world-class monument from concept to successful completion.

The Project

There were many challenging aspects to the design and construction of the Air Force Memorial, and all stem from the necessity of achieving the desired aesthetic impression under all light conditions while ensuring the structural integrity necessary for long service life. Designed by world-renowned architect James Ingo Freed of Pei Cobb Freed, the three stainless steel spires appear seamless as they rise to touch the sky and reach heights of 200, 230, and 270 ft above the ground.

Kyle Johnson, senior associate, Pei Cobb Freed & Partners, described the importance of the aesthetic appearance of the stainless steel welds as follows: "The design envisioned by architect James Ingo Freed required that the spires appear seamless and monolithic, rather than "assembled." In order to achieve this appearance, it was important that the welds be ground flush and finished to match the adjacent glass bead-blasted surfaces, so as to be virtually invisible."

The slender, curved unsupported shapes of the stainless steel spires make them sensitive to wind loading, which makes weld integrity critical, and extensive structural modeling was necessary — Fig. 3. Leo Argiris of ARUP, the consulting engineering firm involved with the project, commented, "The Air Force Memorial's cantilevered, curved spires are subject to dynamic excitations in all wind conditions. An internal damping system consisting of ball-in-box impact dampers (Fig. 4) was installed to minimize this dynamic behavior. As a memorial structure, the design life of the structure was important. In order to extend this life, all the welds were detailed to maximize their fatigue performance. These cyclically loaded welds had to be perfect and blended flush with the surrounding plate. Weld discontinuities such as incomplete fusion, cracking, or porosity could lead to catastrophic failure making high-quality welding and 100% visual and nondestructive inspection critical to the spires' long-term performance."

Tight dimensional tolerances were necessary to achieve the graceful shapes and smooth assembly, which made movement control during all stages of welded fabrication critical. Low-sulfur Type 316L stainless steel (≥ 0.005%) plate was specified for improved corrosion resistance and aesthetic appearance, which made it necessary to also use matching low-sulfur welding wire. The spires were fabricated from 380 tons of 0.75-in.-thick, low sulfur, Type 316L plate from Outokumpu Plate and 4 tons of matching welding wire from Avesta Welding.

The spires are partially filled with concrete to counterbalance their curved shapes and provide added stability, making the addition of internal stiffeners and rebar necessary — Fig. 5. The dampers and their supporting structures were also welded in place. Because of the need to closely control the shape of the spires and produce high-quality, well-blended welds, most of the fabrication was done in shop by Mariani Metal, Etobicoke, Ont., Canada, but with field erection and welding done by Cianbro, Pittsfield, Maine.

The Specifications

The design team realized that tight project specifications were necessary to communicate project requirements and establish tight process controls. ASTM specifications were used to define and to tighten stainless steel plate chemistry and flatness requirements. For example, ASTM A240 was used to establish the plate chemistry and property requirements, and it was further tightened to limit sulfur content (≤ 0.005%). ASTM A480 was used to define dimensional tolerance requirements, and its flatness requirements were tightened to meet project requirements, limiting the maximum deviation from flatness across the entire length and width of each plate to ⅛-in. ASTM A967 and A380 were also used to define surface chemical cleaning and surface preparation expectations.

AWS D1.6, *Structural Welding Code — Stainless Steel*, was used to establish requirements for welder qualification and procedural and inspection requirements. AWS welding consumable specifications (A5.4, A5.9, and A5.22) were specified and tightened to limit the filler metal sulfur content (≤ 0.005%). In addition, it was stipulated that all welds were to be ground flush in order to minimize stress concentrations, increase fatigue life, and as the first step in achieving a seemingly seamless memorial. Furthermore, to ensure that adjacent welded plate surfaces were flush to eliminate stress risers and aesthetic requirements, the fabricator had to maintain ± 1⁄16-in. adjoining plate surface tolerance requirements. The inspectors were certified in accordance with the requirements of AWS QC1, *Standard for AWS Certification of Welding Inspectors*.

Because the wind produces continuous cyclical loading, structural performance of the welds was critical. All complete joint penetration and partial penetration welds were subject to 100% visual inspection. In addition, all welds were inspected using dye penetrant and either ultrasonic or radiographic examination. The comprehensive requirements defined in AWS D1.6 were an invaluable tool to the architects, structural engineers, and metallurgists on the design team because it comprehensively covers welding requirements.

Development

Many factors influenced the selection of welding consumables for the application. Most of the welding was done under shop conditions, although field welding

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Fig. 2 — To ensure an accurate fit, fixtures were utilized during fabrication. (Photo courtesy of Avesta Welding, LLC, Ron Stahura, photographer.)

Fig. 3 — A general layout of the 230-ft-tall spire #2. (Illustration courtesy of Mariani Metal.)

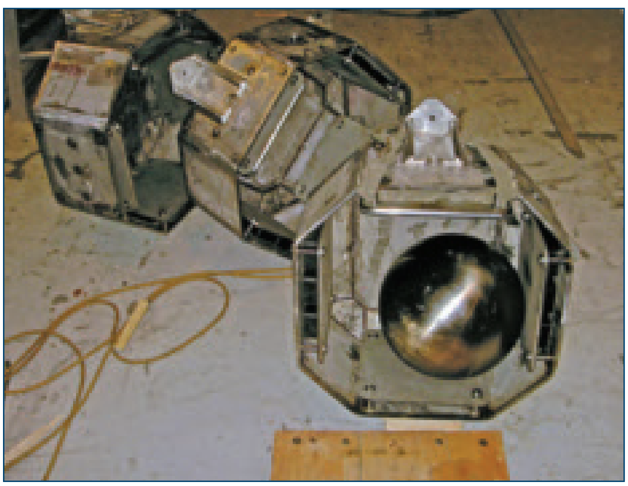

Fig. 4 — Six damper boxes containing a 20-in. steel ball were installed in each spire. (Photo courtesy of Mariani Metal, Len Barnes, photographer.)

was performed during the erection phase. The 316L stainless plate had to be welded with a high-deposition process, capable of producing repeatable, high-quality weld deposits. Mariani Metal's technical welding team had experience in welding stainless steel, but the enormous scope of this project with regard to physical size, lineal feet of weld, joint configurations, aesthetics, and quality assurance presented unique challenges.

After reviewing several welding processes and developing mock-ups (Fig. 6), the decision was made to focus on gas shielded flux cored arc welding (FCAW-G) as the primary welding process for this project. The consumable of choice was ¹⁄₁₆-in. E316LT0-1 gas shielded flux cored wire. This product is ideal for projects requiring high metal deposition rates. In-shop conditions of 11.5 lb/h were easily achieved in the flat and horizontal positions. The flux, which enhances the arc characteristics, contains slag-forming compounds and alloying elements. The weld metal chemistry had a restricted sulfur content (≤ 0.005%), and Avesta Welding was able to supply a single batch lot meeting this requirement.

The composition of the gas shielded flux cored wire was specifically formulated to ensure the correct chemical composition of the weld, good mechanical properties, and optimum welding arc characteristics. Len Barnes, fabrication project manager, Mariani Metal, stated: "The weld bead appearance was very good with virtually no spatter. Since cosmetics were very important on this job, this was monitored closely."

During the initial phase of welding the prototypes, different shielding gases were evaluated. Typically, a 75% argon/25% CO_2 or 100% CO_2 were used with good results. Len Barnes commented, "Since Mariani's facility is capable of mixing its own gas component ratios, we experimented with different combinations and settled on 60% argon/40% CO_2. It produced optimal arc characteristics for this application."

Equipment

In evaluating the welding equipment needed for this job, it became evident that they could primarily use existing capabilities with some minor modifications. Constant voltage power supplies were used since flux cored wire used in combination with an external shielding gas provides exceptional arc characteristics. This eliminated the need for high-technology equipment. The existing wire feeders were simply fitted with unique air-cooled torches specially designed by PAC-MIG, Inc., Wichita, Kans., to withstand the amperage requirements and high duty cycles, while keeping in mind operator comfort during long-duration welds. Knurled ¹⁄₁₆-in. feed rolls were fitted for optimal wire feed speed control.

Automation was used to reduce welder fatigue and maximize arc-on time. A torch was mounted on portable tractors that traveled on tracks held in place with suction cups. The use of suction cups also eliminated the possibility of surface damage.

Weld Joints

The joint configurations had a narrow footprint to meet aesthetic requirements and minimize the amount of weld filler

Fig. 5 — The interior of a modular section showing stiffeners that were welded to the anchor studs. (Photo courtesy of Avesta Welding, LLC, Ron Stahura, photographer.)

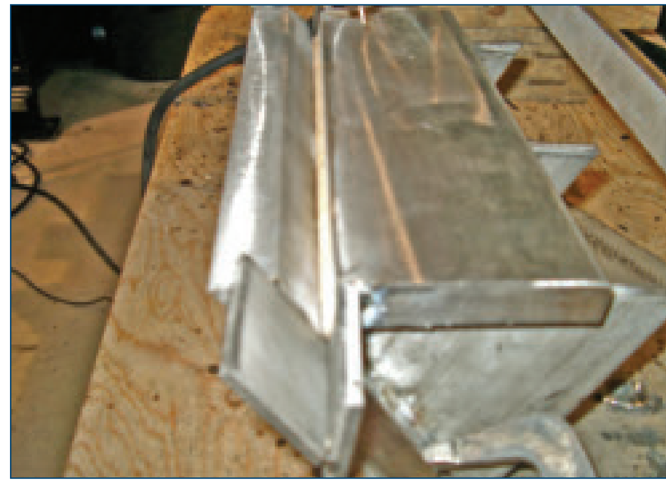

Fig. 6 — Exterior corner joint prepared during weld procedure development. (Photo courtesy of Avesta Welding, LLC, Ron Stahura, photographer.)

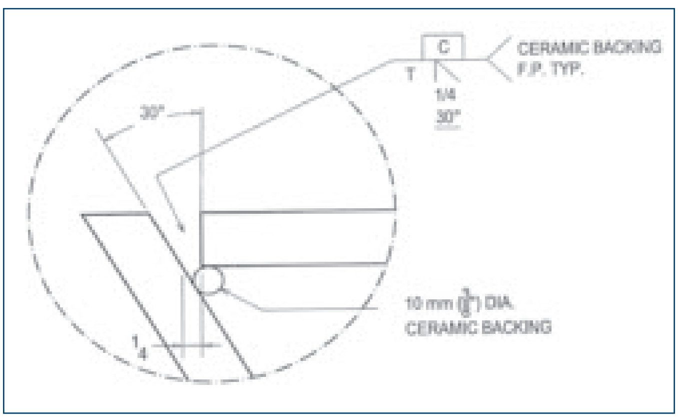

Fig. 7 — Outline of the three exterior spire corner joints. (Illustration courtesy of Mariani Metal.)

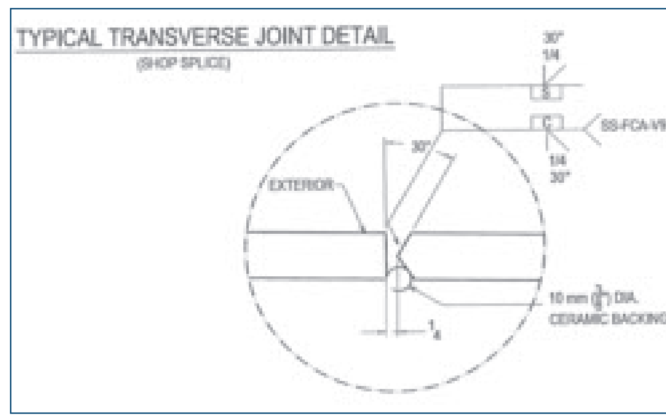

Fig. 8 — Outline of the numerous transverse welds that were used to join each plate in shop and modular section during field erection. (Illustration courtesy of Mariani Metal.)

metal, but this made welding more challenging. Several joint designs were considered, and Figs. 7 and 8 show the configurations selected. The corner- and butt-joint welds were all complete penetration — Fig. 9. Since 100% weld radiographic or ultrasonic inspection was required, procedures were submitted, as mandated per AWS D1.6, to ensure consistent results.

During development of the weld parameters, incomplete fusion and surface imperfections were observed in the root welds. A technical team from Avesta Welding worked closely with Mariani Metal to identify the problem and ensure the product was performing to the project's high standards. The problem was identified and 0.045-in.-diameter wire was used in the root pass. This was applied manually due to accessibility limitations, tight fitup, and the use of ceramic backing bars. In order to gain full access to this narrow groove configuration and maintain a proper 0.75-in. electrode extension, tapered contact tips and nozzles were used.

Excessive electrode extension would result in loss of working voltage and shielding gas coverage, which could induce atmospheric contamination. All of the consecutive passes were automated, utilizing the torch-mounted tractor. These subsequent automated welding steps increased efficiency and produced consistent welds throughout the project.

Stud Welding

Arc studs (concrete anchor type) were welded to the interior spire walls. The 12,000 low-sulfur Type 316L stainless steel studs were 0.75 in. diameter by 8 in. long. The arc stud welding method minimizes the heat-affected zone, ensures 100% penetration of the stud face, and reduces the possibility of distortion marks on the exterior surface. The parameter settings for the welding current were 1480 A, and the arc-on time was 0.8 s. Internal stiffeners were then welded to the studs to maintain structural rigidity. This required two fillet welds on each stud, so there were a total of 24,000 individual welds. All were completed in accordance with AWS D1.6, section 7, stud welding requirements.

Distortion Control

Because of the project's very tight tolerances, minimizing distortion by maintaining tight joint fitup was a significant concern throughout the project. One important aspect of achieving this goal was constant monitoring of the heat input and interpass temperatures. Temperature control is a critical aspect of minimizing distortion and limiting adverse metallurgical effects.

Due to physical property differences, management of the distortion of austenitic stainless is different from carbon steels and requires some adjustment in fabrication procedures. Specifically, stainless steel's heat conductivity is lower than that of carbon steel, and its coefficient of thermal expansion is higher. Barnes indicated, "We did not exceed interpass temperatures of 200°F to ensure that distortion was limited." Temperature was monitored using accurate electronic

Fig. 9 — Cross-sectional view of welded corner joint. (Courtesy of Mariani Metal, Len Barnes, photographer.)

Fig. 11 — The modular section is hoisted for chemical treatments to clean and pickle prior to glass bead blasting. (Photo courtesy of Avesta Welding, LLC, Ron Stahura, photographer.)

Fig. 10 — During the erection phase, 40-ft sections were successfully welded together. The blue outer wrapping protects the exterior finish. (Photo courtesy of Avesta Welding, LLC, Ron Stahura, photographer.)

indicating devices. In addition to increased accuracy, this eliminated a quality control step because foreign products were not introduced into the weld or heat-affected zone.

The average welding parameters were 275 in./min wire feed speed (260 A), 30 V (at 0.75-in. electrode extension), and the deposited weld travel speed rate was 13 in./min. The average heat input for the flux cored welding process was 36 kJ/in., which is well within the typical range that would be considered appropriate. To calculate heat input in kJ/in., the following formula applies.

$$\text{Heat Input} = \frac{A \times V \times 60}{S \times 1000}$$

where A = current (amps)

V= voltage (volts)

S= travel speed (in./min)

$$\frac{260 \times 30 \times 60}{13 \times 1000}$$

Field Welding

Developing segment erection and field welding procedures for this one-of-a-kind project created interesting challenges for Cianbro Construction — Fig. 10. Each prefabricated section brought to the site was about 40 ft long. Working enclosures were necessary to shield each weld area from weather conditions during fabrication and surface finishing. Because the gas shielded flux cored process was used, air movement had to be minimized and welding could not occur if there was exposure to moisture.

Furthermore, chemical pickling of the weld areas was necessary to restore corrosion resistance and dull the finish. On a project of this scale, chemical treatments must be enclosed since the pickling product cannot be applied if there is direct sunlight or exposure to moisture, and it was necessary to have controlled collection of the rinse water used to remove the acid-based pickling product.

The field welding had to be done in the horizontal position, which required different procedures. In shop conditions, all of the fabrications were arranged in the favorable flat position. During the erection phase, this was no longer possible and fitup adjustments were necessary. The Avesta Welding technical team worked closely with Cianbro to develop field welding procedures, and it was determined that 0.045-in., 316LT1-1 all-position flux cored wire was the most appropriate choice. This product's smaller weld pool, combined with faster freezing arc characteristics, provided greater control of the molten weld pool. While gravity creates a whole new array of challenges, there is usually a welding consumable engineered for the application.

Because the joint configuration had to be welded from both sides, a planned sequence of weld passes was applied to the internal and external faces to minimize distortion. Prior to welding, temporary holding brackets and tack welds were put in place to ensure alignment throughout the welding process. Tight alignment was critical if the project was to achieve a visually seamless surface after welding and surface finishing. The result was a very effective distortion control plan.

Cleaning

In accordance with AWS D1.6, *Structural Welding Code — Stainless Steel*, section 5.2.1.1, surfaces on which weld metal is to be deposited must be clean and free from organic contaminants and surface oxides prior to welding. Hydrocarbons or sulfur-bearing products can have detrimental effects to stainless steel weld deposits. This cleaning was also done in accordance with ASTM A380 and A967. Standard procedures for cleaning between passes on single and multipass welds were also followed. Stainless steel wire brushes or grinding with wheels dedicated to stainless steel processing were used to remove any slag or heat oxide.

Because of aesthetic requirements, weld blending was a paramount concern. During shop fabrication, welds were ground flush with the surrounding plate surfaces. A 50-grit finish was applied to match the directionality of the ground finish on the surrounding plate. Then the entire section was cleaned to remove any fingerprints, dirt, and oils prior to the pickling process.

Each 40-ft-long, shop-fabricated segment was then chemically pickled to ensure restoration of the stainless steel's corrosion resistance and to dull the surface so that aesthetic goals could be achieved — Fig. 11. Because of the size of the fabrications, Avesta Welding's Red One™ spray pickling gel was applied to about 53,000 square feet of the entire exterior surface. This product was preferred because it was capable of producing the desired performance under the wide range of production temperatures.

The use of a gel product permitted rapid uniform coverage, which improved control over the pickling process and final appearance. This was done in accordance with ASTM A380. Deionized water was used to wash off the residual chemical pickling product. This cleaning prevented mineral staining of the surface, which could otherwise occur if potable water containing more than 200 ppm solids were used. The final finishing step was glass bead blasting. If there had been dirt accumulation or fingerprinting between pickling and bead blasting, the surface was cleaned prior to the final finishing step.

The same grinding, chemical pickling, and glass bead finishing steps were used to blend in the field welds after shielding the surrounding surfaces. Because glass bead blasting dents but does not remove the surface, the final finish should retain the corrosion performance advantage of chemical pickling.

Conclusions

Due to the complexity and unique characteristics of the Air Force Memorial fabrication process, innovative techniques were necessary. Close supplier, fabricator, and design team cooperation was needed during development and fabrication to meet the unusual tolerance, structural, and aesthetic requirements of this project. Maximum use and tightening of existing specifications in combination with stringent inspection were critical to achieving success.◆

Acknowledgments

The authors would like to acknowledge the assistance of Mariani Metal, the Air Force Memorial Foundation, ARUP, and Pei Cobb Freed.

Works Consulted

Avesta Welding Manual: Practice and Products for Stainless Steel Welding. Martin Larén, editor, Avesta Welding AB.

May 26, 2009

"Freedom is Not Free". Electralloy proud to play a role in the construction of the Korean War Veterans Memorial.

(Oil City, PA)—Electralloy is proud to have played a role in the construction one of Washington D.C.'s newest memorials, the Korean War Veterans Memorial, an impressive tribute to the many who fought in the Korean War.

Dedicated in 1995, the Korean War Veterans Memorial features statues of 19 larger-than-life-size soldiers on patrol, carefully making their way through unknown terrain. The statues were sculpted by Frank Gaylord of Barre, Vt., and cast by Tallix Foundries of Beacon, N.Y. Electralloy supplied the 316L modified master alloy ingot to Tallix specifically for use in the construction of the statues.

The memorial commemorates the sacrifices of the 5.8 million Americans who served in the U.S. armed services during the three-year period of the Korean War. The war was one of the most hard fought in our history. During the War's duration, from June 25, 1950 to July 27, 1953, a total of 54,246 Americans died in support of their country.

A granite wall at the monument bears the simple message, inlaid in silver: "Freedom Is Not Free".

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Fundamentals

of Small Parts Resistance Welding

General Principles

Resistance welding is a thermo-electric process in which heat is generated at the interface of the parts to be joined by passing an electrical current through the parts for a precisely controlled time and under a controlled pressure (also called force). The name "resistance" welding derives from the fact that the resistance of the workpieces and electrodes are used in combination or contrast to generate the heat at their interface.

Key advantages of the resistance welding process include:

- Very short process time
- No consumables, such as brazing materials, solder, or welding rods
- Operator safety because of low voltage
- Clean and environmentally friendly
- A reliable electro-mechanical joint is formed

Resistance welding is a fairly simple heat generation process: the passage of current through a resistance generates heat. This is the same principle used in the operation of heating coils. In addition to the bulk resistances, the contact resistances also play a major role. The contact resistances are influenced by the surface condition (surface roughness, cleanliness, oxidation, and platings).

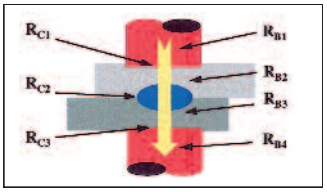
The general heat generation formula for resistance welding is:

Heat = I2 x R x t x K

Where "I" is the weld current through the workpieces, "R" is the electrical resistance (in ohms) of the workpieces, "t" is the weld time (in hertz, milliseconds or microseconds), and "K" is a thermal constant. The weld current (I) and duration of current (t) are controlled by the resistance welding power supply. The resistance of the workpieces (R) is a function of the weld force and the materials used. The thermal constant "K" can be affected by part geometry, fixturing and weld force.

The bulk and contact resistance values of the workpieces, electrodes, and their interfaces both cause and affect the amount of heat generated. The diagram (above right) illustrates three contact and four bulk resistance values, which, combined, help determine the heat generated.

BULK RESISTANCE is a function of temperature. All metals exhibit a Positive Temperature Coefficient (PTC), which means that their bulk resistance increases with temperature. Bulk resistance becomes a factor in longer welds.

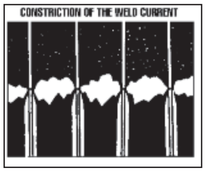


CONTACT RESISTANCE is a function of the extent to which two surfaces mate intimately or come in contact. Contact resistance is an important factor in the first few milliseconds of a weld.

The surfaces of metal are quite rough if they are examined on a molecular scale. When the metals are forced together with a relatively small amount of force, some of the peaks make contact.

On those peaks where the contact pressure is sufficiently high, the oxide layer breaks, forming a limited number of metal-to-metal bridges. The weld current is distributed over a large area as it passes through the bulk metal. However, as it approaches the interface, the current is forced to flow through these metallic bridges. This "necking down" increases the current density, generating enough heat to cause melting. As the first of these bridges melt and collapse, new peaks come into contact, forming new bridges and additional current paths. The resistance of the molten metal is higher than that of the new bridges so that the current flow transfers from bridge-to-bridge. This process continues until the entire interface is molten. When the current stops, the electrodes rapidly cool the molten metal, which solidifies, forming a weld.

Exaggerated cross-section of two pieces of metal indicates formation of metallic bridges that result in high current density.



Subsequent melting and the formation of new bridges allow the weld to be formed.

HEAT BALANCE – During resistance welding, part of the heat generated is lost to the surroundings by conduction (heat transfer through solids), convection (heat lost from exposed surfaces by air-cooling), and radiation (does not require a medium). Heat balance is a function of part material and geometry, electrode material and geometry, polarity, and the weld schedule. The goal of good resistance welding is to focus the heat generated close to the weld interface at the spot where the weld is desired.

In general, the highest resistance results in the highest heat assuming that the resistance welding power supply can produce sufficient energy to overcome the resistance. Thus, dissimilar parts and electrode combinations are preferred since their dissimilarity results in higher resistance. For example, conductive electrodes, e.g. copper, are used to weld resistive materials such as stainless steel or nickel, and resistive electrodes, e.g. molybdenum, are used to weld conductive materials, such as copper or gold.

To force the metals together, electrode pressure (force) provided by the weld head, is equally important. Heat, generated by the resistance of the workpieces to the flow of electricity, either melts the material at the interface or reduces its strength to a level where the surface becomes plastic. When the flow of current stops, the electrode force is maintained, for a fraction of a second, while the weld rapidly cools and solidifies.

There are three basic types of resistance welding bonds:

SOLID STATE BOND – In a Solid State Bond (also called thermo-compression Bond), dissimilar materials with dissimilar grain structure, e.g. molybdenum to tungsten, are joined using a very short heating time, high weld energy, and high force. There is little melting and minimum grain growth, but a definite bond and grain interface. Thus the materials actually bond while still in the "solid state." The bonded materials typically exhibit excellent shear and tensile strength, but poor peel strength.

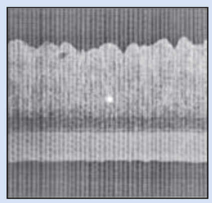
FUSION BOND – In a Fusion Bond, either similar or dissimilar materials with similar grain structures are heated to the melting point (liquid state) of both. The subsequent cooling and combination of the materials forms a "nugget" alloy of the two materials with larger grain growth. Typically, high weld energies at either short or long weld times, depending on physical characteristics, are used to produce fusion bonds. The bonded materials usually exhibit excellent tensile, peel and shear strengths.

REFLOW BRAZE BOND – In a Reflow Braze Bond, a resistance heating of a low temperature brazing material, such as gold or solder, is used to join either dissimilar materials or widely varied thick/thin material combinations. The brazing material must "wet" to each part and possess a lower melting point than the two workpieces. The resultant bond has definite interfaces with minimum grain growth. Typically the process requires a longer (2 to 100 ms) heating time at low weld energy. The resultant bond exhibits excellent tensile strength, but poor peel and shear strength.

HEAT AFFECTED ZONE (HAZ) is the volume of material at or near the weld which properties have been altered due to the weld heat. Since the resistance welding process relies on heating two parts, some amount of HAZ is inevitable. The material within the HAZ undergoes a change, which may or may not be beneficial to the welded joint. In general, the goal in good resistance welding is to minimize the HAZ.

Solid State Bond

Fusion Bond



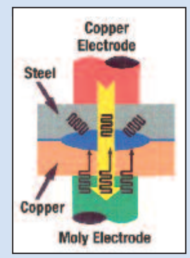
Reflow Braze Bond

Materials

The physical metallurgy of the materials to be welded determines the application of the resistance welding process variables. In general there are two categories of metals to be welded: "Conductive" (such as aluminum, copper, silver and gold), and "Resistive" (steel, nickel, inconel, titanium, tungsten, molybdenum) with a third, small, middle ground category occupied primarily by brass. In general, electrically conductive materials are also more thermally conductive and are softer.

These categories apply equally to both the workpieces to be joined and to the electrodes. As discussed earlier, higher electrical resistance produces higher heat and better welds. Thus the "rule of opposites" applies to matching electrodes to workpieces to be welded. The general rule (with a few exceptions such as aluminum and beryllium copper) is to utilize conductive electrodes against resistive parts and resistive electrodes against conductive parts. By extension, when welding dissimilar materials, the upper and lower (or anode and cathode) electrodes must be of different materials to each other in order to apply the "rule of opposites."

When welding a resistive material to a conductive material, one should use conductive electrodes (copper) on resistive parts (steel) and resistive electrodes (moly) on conductive parts (copper).



Material Properties

ELECTRICAL RESISTIVITY – Low resistance metals, e.g. copper, require larger currents to produce the same amount of heat. Low resistance materials also exhibit low contact resistance.

THERMAL CONDUCTIVITY – Metals with high thermal conductivity, e.g. copper, exhibit high electrical conductivity. The heat generated in high thermal conductivity materials is rapidly conducted away from the region of the weld. For metallic materials, the electrical and thermal conductivity correlate positively, i.e. materials with high electrical conductivity (low electrical resistance) exhibit high thermal conductivity.

THERMAL EXPANSION – Softer metals exhibit a high coefficient of expansion (CTE); whereas harder materials, such as tungsten, exhibit a low CTE. A CTE mismatch between two workpieces can result in significant residual stresses at the joint which, when combined with the applied stresses, can cause failure at lower pull strengths.

HARDNESS AND STRENGTH – In seeming contradiction to the "rule of opposites," hard material workpieces generally require harder electrodes (which exhibit lower conductivity) due to the higher weld forces required.

PLASTIC TEMPERATURE RANGE is the temperature range in which a material can be deformed easily (melt) under the application of force. Steels and alloys exhibit a wide plastic temperature range and thus are easy to fusion weld. The natural elements, copper and aluminum exhibit a narrow plastic temperature range. Accurate control of the weld temperature is critical to avoid excessive melting.

POLARITY should be considered when using all power supply technologies. If any of the interfaces of a resistance weld (between electrodes and workpieces or between the workpieces to be joined) is composed of dissimilar materials, that interface will heat or cool depending on the polarity of the applied potential. This effect is dominant only in the first few milliseconds of a weld. Although it is more dominant for welds of short duration, it affects the weld quality and electrode wear of long welds as well. The effects of polarity can be minimized or controlled via the use of contrasting size electrode forces and/or weld pulses of alternating polarity.

Other material related parameters affect the resistance welding process, and must therefore be controlled. These parameters include oxide contamination, plating inconsistencies, surface roughness and heat imbalance.

OXIDE CONTAMINATION causes inconsistent welds by inhibiting intimate contact at the weld joint. Preventive actions include pre-cleaning the workpieces, increasing the weld force to push aside the oxide, and/or using a cover gas during welding to prevent additional oxide formation.

PLATING INCONSISTENCIES include variations in plating thickness, degree of oxide contamination in the plating and the type of plating. Proper control of workpiece plating reduces the chance of weak or inconsistent welds and/or electrode sparking or sticking to the workpieces. Electroplating is much preferred over electroless plating.

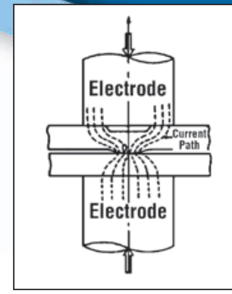
SURFACE ROUGHNESS can also result in localized over/under heating, electrode sticking and/or material expulsion. The same rule applies to all three material parameters: any surface condition that impairs intimate workpiece contact to each other and to the electrodes will inhibit good welding.

HEAT IMBALANCE and heat sinks can result in unexpected heat loss or misdirection. Heat must be concentrated at the point of the weld to insure correct and consistent welds.

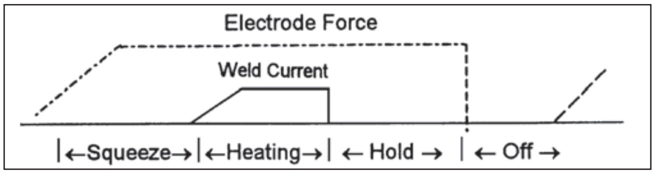
PROJECTIONS (low thermal mass islands) are one method of insuring proper heat balance in difficult applications when there exists a 5:1 size difference between the parts to be welded. Another method is to vary the size, shape and/or material of the welding electrode.

Advantages of Projections in Micro Spot Welding

By providing a projection on the surface of one of the workpieces, the current and force can be focused into the small area of the projection to produce heat at the desired weld location. Projection welding can also extend electrode life by increasing the electrode contact area and decreasing the current density at the surface of the electrode. Projection welding is effective even if the weldments are thick.



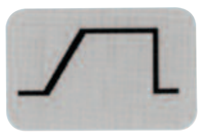
Basic Weld Schedule



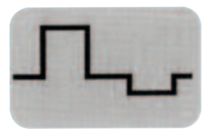
This basic weld schedule forms the basis for all microwelding schedules. The amplitude and duration of all force and heating parameters can be defined in the "weld schedule." The four critical parameters are: electrode force, squeeze time, weld pulse and hold time. Variations can also be dual pulse and other sequences shown below.

Examples of welding sequences (also called heat profiles) include:

Single Pulse:* *Use on flat un-plated parts

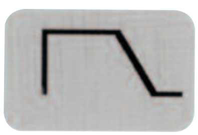


Up Slope: Use on hard, irregular shaped, oxidized parts and aluminum parts

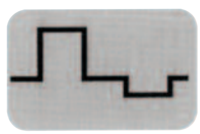


Preheat/Postheat: Use on refractive parts

Quench/ Temper



Down Slope: Used to reduce marking and embrittlement



Unbalanced: Use on polarity sensitive parts

Roll Spot: Use to make non-hermetic seam welds

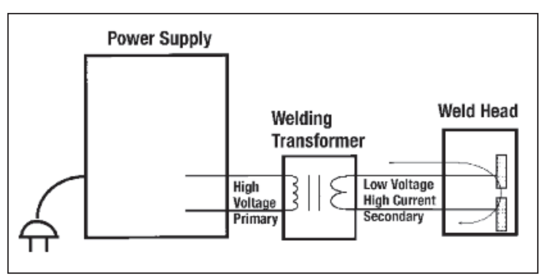
Weld Force

A key parameter of all three types of resistance welding is weld pressure or force. The proper and consistent application of force improves the mating of the materials increasing the current paths, reducing the interface resistance, and insuring that any oxide barriers between the workpieces are broken through. Repeatable force control insures repeatable weld quality through consistent electrical contact resistance and consistent heat balance. Force control can also be used to trigger welding energy when a pre-determined force level has been achieved, often called "force firing." Optimum welds are achieved when the applied force is precise, repeatable, controlled by time schedule, used to fire the power supply, and regulated both to reduce the initial impact and not to become excessive after the weld. **Weld force control is equally as important as weld energy and time control.**

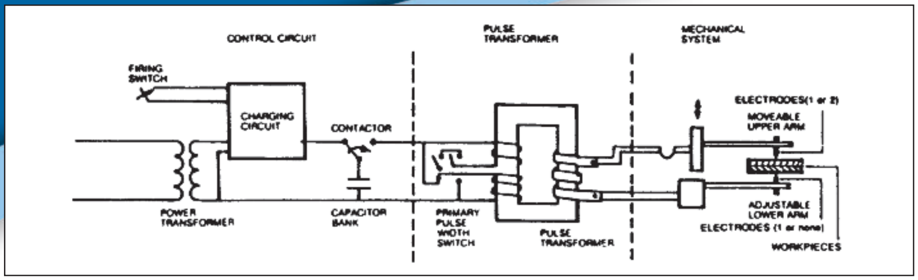
Energy and Time

The power supply with either an internal or external transformer both powers and controls the application of heat and time in the resistance welding process. In general terms, resistance welding applies high current with low voltage.

The generic schematic is:



In simple terms the resistance welding power supply transforms, modulates and controls the electrical energy of the power line and applies it to the weld according to a user defined or user programmed "weld schedule." Depending on the complexity and intricacy of the power supply the user can program from one to more than 100 attributes and permutations of the welding process, and, using a microprocessor, store these attributes as a uniquely defined "weld schedule."



Functional Diagram of a Stored Energy Resistance Welding Machine

Stored Energy (Capacitive Discharge):

The stored energy welding power supply, commonly called a Capacitive Discharge or CD Welder, extracts energy from the power line over a period of time and stores it in welding capacitors. Thus, the effective weld energy is independent of line voltage fluctuations. This stored energy is rapidly discharged through a pulse transformer producing a flow of electrical current through the welding head and workpieces.

Capacitive discharge power supplies are rated in accordance with the amount of energy they store and the welding speed. The energy stored, expressed in watt-seconds (joules), is the product of one-half the capacitance of the capacitor bank and the square of the applied voltage. The energy delivered to the electrodes is considerably less than this value because of losses in the primary and secondary circuits.

Some power supplies provide a "Dual Pulse" feature which allows the use of two pulses to make a weld. The first pulse is generally used to displace surface oxides and plating, and the second pulse welds the base materials. This feature also reduces spitting.

Power Supply Technologies

PULSE TRANSFORMERS – are designed to carry high secondary currents, typically up to 10,000 amps. Welds made with a capacitive discharge system are generally accomplished with a single, very short weld pulse with a duration of from 1 to 16 milliseconds. This produces rapid heating that is localized at the welding interface. The length of the output pulse width can normally be modified by changing taps on the pulse transformer. Polarity switching is a convenience when the machine is used to weld a wide variety of polarity sensitive dissimilar metals.

In practical applications, the short pulse is used to weld copper and brass, which require fast heating; the medium pulse is used to weld nickel, steel and other resistive materials and the long pulse is also used to weld resistive materials and to reduce sparking and electrode sticking.

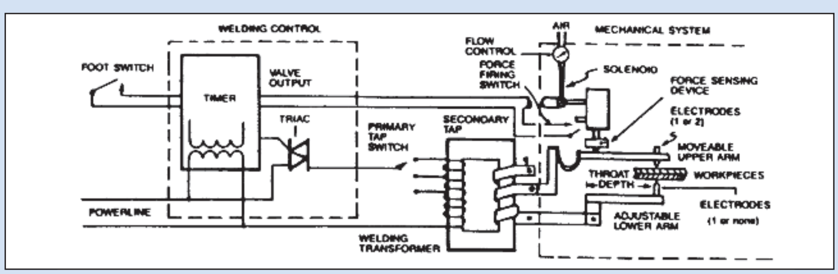
Direct Energy (AC)

The AC welder derives its name from the fact that its output is generally a sine wave of the same frequency as the power line. It extracts energy from the power line as the weld is being made. For this reason, the power line must be well regulated and capable of providing the necessary energy. Some AC welders (including all Miyachi Unitek AC welders) include a line voltage compensation feature to automatically adjust for power line fluctuations. In its simplest form, the AC welder consists of a welding transformer that steps down the line voltage (normally between 480 to 100 volts) to the welding voltage (typically 2 to 20 volts). The welding current that flows through the secondary of the transformer, and its connected load, is very high, ranging from 10 to more than 100,000 amps. The welding current is allowed to flow for very short periods of time, typically .001 to 2 seconds. AC welders can operate at rates up to 5-6 welds per second.

AC Welding Systems are generally composed of the three elements. The Welding Transformer, the Welding Control, and the Mechanical System.

WELDING TRANSFORMERS – are used in AC machines to change alternating current from the power line into a low-voltage, high amperage current in the secondary winding. A combination of primary and/or secondary taps on the welding transformer are commonly used to provide a macro adjustment of the welding current, as well as adjustment of secondary voltage. Transformer ratings for AC machines are expressed in KVA (kilovolt-amperes) for a specified duty cycle. This duty cycle rating is a thermal rating, and indicates the amount of energy that the transformer can deliver for a stated percentage of a specific time period, usually one minute, without exceeding its temperature rating. The RMS Short Circuit Secondary Current specification indicates the maximum current that can be obtained from the transformer. Since heating is a function of the welding current, this parameter gives an indication of the thickness of the materials that can be welded.

Recent advances in AC welding technology have adapted constant current feedback control at the line frequency (50 or 60 Hz) which can be useful for welds longer than 5 cycles (82-100 milliseconds) by automatically adjusting the power supply parameters.



Functional Diagram of an AC Resistance Welding Machine

High Frequency Inverter (HFDC)

High Frequency Inverter Welders use submillisecond pulsewidth modulation (switching) technology with closed-loop feedback to control the weld energy in submillisecond increments. Three phase input current is full wave rectified to DC and switched at (up to) 25 kHz to produce an AC current at the primary of the welding transformer. The secondary current is then rectified to produce DC welding current with an imposed, low-level, AC ripple. The high-speed feedback circuitry enables the inverter power supply to adapt to changes in the secondary loop resistance and the dynamics of the welding process. For example, a 25 kHz inverter power supply adjusts the output current every 20 microseconds after rectification, which also allows the weld time (duration of current) to be controlled accurately in increments as small as 0.1 milliseconds.

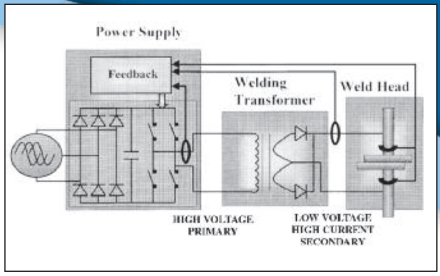
The high frequency closed loop feedback can be used to control (maintain constant) either current, voltage, or power while also monitoring another of the same three parameters.

Additional benefits of high frequency switching technology include reduced power consumption, smaller welding transformers, and the use of a very short pre-weld "check pulse" to test electrode and parts positioning prior to executing a weld. The result of this pre-weld check can be used to inhibit the weld by setting check limits.

CONSTANT CURRENT can be used for 65% of all welding applications including those that exhibit low contact resistance, small variability in contact resistance, flat parts, and multiple part "sandwiches."

CONSTANT VOLTAGE can be used for applications where the workpieces do not have flat surfaces, e.g. crossed wires, and where the resistance varies significantly, and for extremely short welds (less than 1 millisecond).

CONSTANT POWER can be used for applications with significant variations in electrical resistance from weld to weld, including applications where the plating erodes and builds-up on the face of the welding electrodes.



Functional Diagram of an HFDC Resistance Welding Machine

Due to their extensive programmability, small transformer size, and robustness, high frequency inverter power supplies are generally the best choice for automation applications.

Transistor Direct Current (Linear DC)

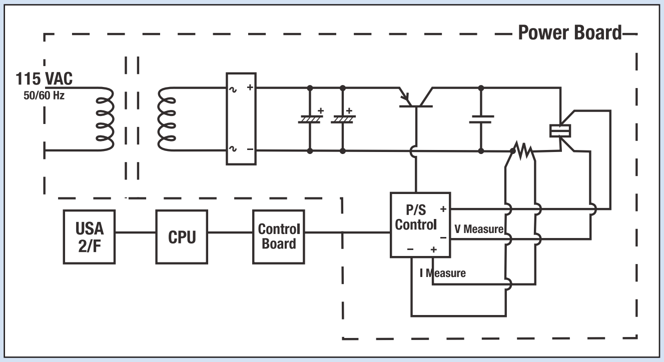
The transistor direct current power supplies (also called "Linear DC") produce much the same results as the high frequency inverter by using a high number of power transistors as the direct energy source. This technology provides clean, square wave forms with extremely fast rise time. Used primarily in constant voltage feedback control, transistor DC power supplies are effective in thin foils and fine wire welding applications and for extremely short welds.

Linear DC welders utilize transistor controlled feedback enabling total feedback response times of less than 5 μS. The term Linear DC comes from the waveform that is output from the power supply. No transformer is utilized. The primary limitation to Linear DC technology is the low duty cycles, typically much less than 1 weld per second at less than rated output.

Typically, constant voltage feedback is utilized in conjunction with short weld pulses. Because the feedback response is so rapid, high energy welds with extremely short duration can be used without weld splash or arcing. These short pulses limit the heat stress and the size of the heat affected zone on the weldments. This provides a stronger more ductile weld joint, along with less part deformation, less discoloration, and significantly longer electrode life.

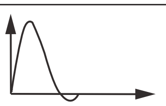
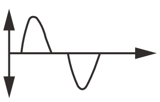
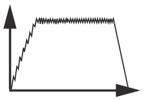
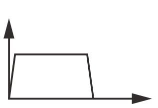
Constant voltage feedback is chosen for two reasons: its ability to prevent arcing and to provide the optimum weld power distribution based on the part resistance. If for some reason the weldments collapse faster than the weld head can follow up, arcing usually occurs. When constant voltage feedback is applied with the feedback response times capable by Linear DC welding this arcing is minimized.

Transistor DC units tend to be larger and heavier than other resistance welding power supply technologies.



Functional Diagram of a Linear DC Resistance Welding Machine

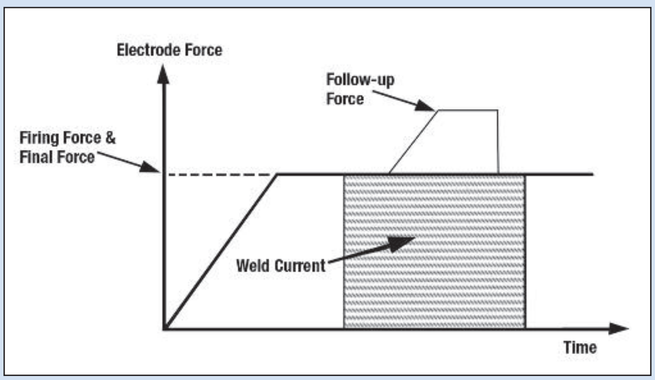
Power Supply Technology Comparison

Power Supply	Typical Cycle Time	Typical Bond Type	Repetition Rate	Advantages	Limitations	Waveform
Capacitor Discharge (CD) provides a uni-polar fixed duration weld current pulse of short duration with a fast rise time.	1-16 msec	Solid State	≤ 2/sec.	Rugged and inexpensive. Suitable for highly conductive materials.	Open loop. Discharge "self-regulating."	
Direct Energy (AC) provides a uni-polar or bi-polar, adjustable duration weld current pulse with rise times dependent on the % weld current setting.	>8 msec	Fusion, Reflow, Braze	≤ 5/sec.	Rugged and inexpensive.	Poor control at short cycle times.	
High Frequency Inverter (HFDC) provides a uni-polar, adjustable duration weld current pulse with an adjustable moderate-to-fast, rise time.	1,000 msec	Fusion, Solid State, Reflow, Braze	≤ 10/sec.	Excellent control and repeatability. High current capacity; high duty cycle.	Higher cost.	
Transistor or Linear DC (DC) provides a uni-polar, adjustable duration weld current pulse with a fast voltage rise time, and square voltage wave.	0.010 –9.99 msec	Solid State	≤ 1/sec.	Suitable for amorphous materials, thin foils, fine wires. Excellent control and repeatability.	Higher cost maintenance. Limited duty cycle. One piece construction.	

Weld Head Technologies

As described earlier, the application and control of force during the resistance welding process is extremely important. The mechanical system to do so is generally referred to as the weld head. The weld head (including the welding electrodes), functions to force the workpieces together and hold them during the weld. The weld head provides the current path, welding pressure or force, triggers (initiates) the weld current, provides follow-up force as the workpieces melt together, and cools the workpieces after the weld. Development of a weld head force schedule is equally as important as development of a power supply schedule. The ideal force schedule insures that proper electrical contact resistance and proper heat balance are both achieved and maintained between the workpieces and the electrodes. Force is measured in pounds (lbf), Kilograms (Kgf) or Newtons (N or dN).

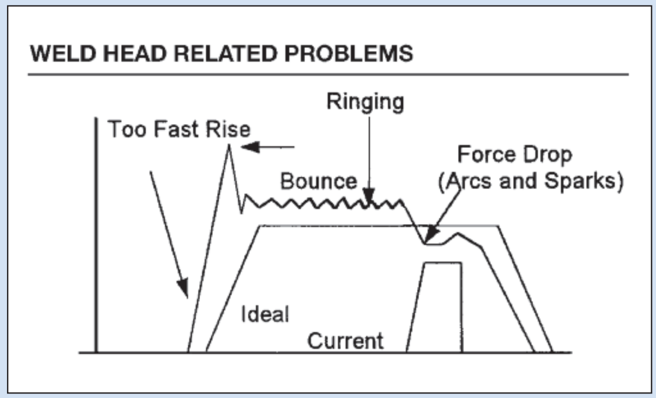
In small parts resistance welding the weld heads are of linear motion design with linear races or bearings and spring-driven force adjustment. Low inertia weld heads with low mass electrode holders and low friction bearings provide fast "follow-up." "Follow-up" refers to the capacity of the weld head to accelerate and remain in contact with the workpieces as the workpieces become molten and melt together during the weld.



Recent advances in weld head design include electronic weld heads where weld head movement and force are electronically controlled, and/or electronically monitored, via a precise schedule. The precise control of an electronic weld head can program the timing of each element of the force profile, minimize impact force, duplicate force profile between weld stations, and provide electronic evidence of the actual weld force profile. The control for electronic weld heads can be independent of, or integrated into, resistance welding power supplies. The "Electrode Force" diagram, below left, depicts the precisely controlled force profile, including follow-up force, of an electronic weld head.

Today, force sensors, strain gauges, and motion sensors/transducers can be built into a mechanical or electronic weld head for control and/or monitoring purposes.The weld head must be designed and operated to preclude these potential problems.

The most typical weld head related problems are depicted in the drawing below.



Lastly, the use of properly designed fixtures to hold the workpieces in fixed position during welding is highly desirable. The workpieces must be in a fixed rigid position prior to the initiation of the resistance welding process. In manual welding, operators should be used to load workpieces in a fixture, not to hold workpieces during the welding process. Additionally, the fixtures should be constructed to insure that the welding surface of the electrodes fit squarely and completely against the workpieces.

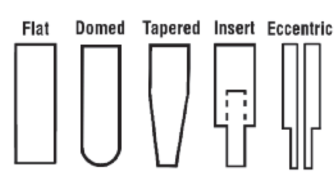
Welding Electrodes

Welding electrodes are installed in the weld head to touch and maintain contact with the workpieces through the full weld schedule. The MATERIALS section (pg. 2) discussed the "rule of opposites" and the criteria for selecting the electrode material.

The welding electrodes play three different roles in resistance welding: maintaining uniform current density, concentrating current at welding points, and maintaining thermal balance during welding. Electrodes are available in many shapes, with the most common shown at right. Electrode material and shape are determined by considering the force necessary for welding and the thermal conductivity of the workpieces.

In conventional macro-welding, e.g. car body assembly, the electrodes are made of copper alloys and usually water-cooled. However, in micro-welding, the electrodes are made of a wide variety of conductive and refractory materials depending on the parts to be joined, and are air-cooled.

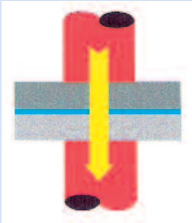
Common Electrode Shapes:



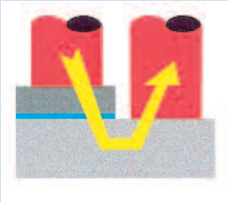
The size of the weld will not be larger than the electrode face. Therefore, it is important to utilize electrodes of the same tip diameter as the desired weld nugget. The current density at the workpiece interfaces varies as the square of the diameter of the electrode face. Electrode positioning is critical: electrodes should be positioned where the weld is desired, should generally not overhang the edges of the part (except in wire and small terminal welding), should not bend, should be perpendicular to the plane of the workpieces, should maintain constant diameter (constant area) as they wear, and should be cleaned and dressed regularly. Electrodes should be dressed with 600 grit silicon carbide paper or polishing disk pulled with light force in one direction only. Electrodes should be replaced when the tip is damaged or blows out. It is best to have all electrode tips reground regularly by a qualified machine shop.

The choice of electrode configurations is determined by the geometry of the workpieces, the application, and the desired current path.

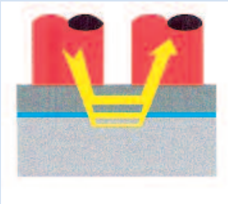
The four basic electrode configurations are:



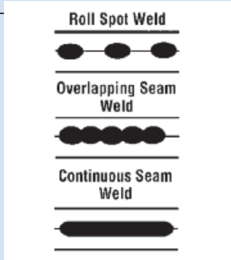
Opposed (Direct) Welding *is the most commonly used type of resistance welding. The welding current flows directly from one electrode to the other, through the weldments.*



Step (Indirect) Welding *is often used when the workpieces are configured in such a way that only one side of the workpiece is accessible with an electrode, or there is a large thermal imbalance. The welding current flows from the first electrode, through the workpiece, through the area of the weld, through the other workpiece and into the other electrode.*



Series Welding *is also used when only one side of the weldment is accessible with electrodes. This form of welding has the advantage of making two weld nuggets at one time. However, series welding is generally less controllable because of the many shunt paths available to the welding current.*



Seam Welding *is another variation on resistance spot welding. in this case, the welding electrodes are motor-driven wheels rather than stationary rods. The result is a "rolling" resistance weld or seam weld used to join two sheets together. Overlapping and continuous seam welds can produce gas- or liquid- tight joints.*

Common Electrode Materials

RWMA 1 – COPPER CADMIUM ALLOY – 70B Rockwell Hardness, 90% conductivity. Used for welding aluminum and tin plate. Not available from Miyachi Unitek. GLIDCOP is a substitute.

RWMA 2 – COPPER CHROMIUM ALLOY – 83B Rockwell Hardness, 85% conductivity. Used for welding steels, nickel alloys and other high resistance materials.

GLIDCOP – DISPERSION STRENGTHENED COPPER with 0.15% ALUMINUM OXIDE – 68B Rockwell Hardness, 92% conductivity. Longer life, greater thermal stability, higher strength than RWMA 2. Generally interchangeable with RWMA 2 without changing schedules.

RWMA 3 – COPPER COBALT BERYLLIUM ALLOY – 100B Rockwell Hardness, 48% conductivity. Used for welding high resistance materials requiring high weld forces.

RWMA 11 – COPPER TUNGSTEN ALLOY – 99B Rockwell Hardness, 46% conductivity. Usually inserted into an RWMA 2 shank. Used for welding cuprous and precious metals. Used for light projection welding dies.

RWMA 13 – TUNGSTEN –70A Rockwell Hardness, 32% conductivity. Usually inserted into an RWMA 2 shank. Cannot be machined but may be ground to the desired shape. Used to weld non-ferrous metals such as copper and brass.

RWMA 14 – MOLYBDENUM – 90B Rockwell Hardness, 31% conductivity. Usually inserted into an RWMA 2 shank. Machineable. Used for welding copper, silver, gold and their alloys.

Weld Quality and Process Validation

The monitoring of any manufacturing process is essential for achieving the "six sigma" goals of production quality. Often the cost of monitoring equipment is significantly less expensive than the cost ramifications of the field failure of a single weld.

Destructive testing methods include tensile pull-test, peel tests, shear tests, corrosion tests, optical microscopy, cross-section inspection, and scanning electron microscopy. These tests are typically used to qualify processes initially as well as periodically. On-line monitoring of key resistance welding parameters is a more effective method of continuous weld quality.

Weld monitors are devices that measure one or more specific electrical and/or mechanical parameters that dynamically change during the welding process. These measurements may include weld current, voltage drop across the electrodes, workpiece expansion and deformation, electrode force, electrode movement (displacement), size of the electrode face, acoustic energy emitted while the weld is being formed, and temperature of the workpieces. Variations in the thickness, tensile strength, hardness, surface finish and cleanliness of the workpieces have a significant effect on weld quality. As discussed earlier, the shape of the electrode face also affects weld quality. Modern measurement techniques make it possible to accurately measure the energy and pressure used to make a resistance weld. Weld monitoring is effective to the extent that the electrical and mechanical measurements made during the welding process reflect the variations in the physical properties of the workpieces and the welding equipment.

Today's state-of-the-art resistance welding monitors can measure the following parameters practically and effectively:

- Current
- Voltage
- Force
- Displacement (weld collapse)

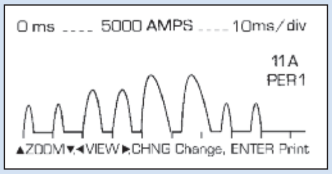
Combining these measurements in various ways can provide the user practical information regarding weld quality.

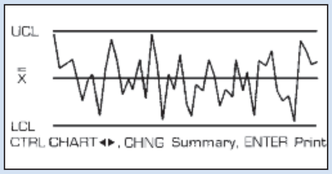
Pre-weld resistance checks can be used to detect the absence of parts or major irregularities in part thickness or fit-up.

Force monitoring can be used as a preventive measure to prevent excessive impact or weld force and as a diagnostic tool. Force monitoring is generally used as a process control tool. It is used less often as a quality evaluation tool.

Extensive experiments are normally required in order to determine which combination of measurement parameters correlates with the quality of their specific parts. Once correlation is verified in a production environment over a reasonable time, the weld monitor becomes a vital manufacturing tool. If the user carefully controls the quality of the workpieces and uses good manufacturing process control, a weld monitor can provide the necessary electrical data for statistical process control which in turn should increase quality and reduce manufacturing costs.

Modern weld monitors integrate with or include statistical process control (SPC) software. SPC software packages can perform statistical calculations, generate X-bar and R-control charts, and provide summary information of the weld data. A few monitors can compare multiple weld parametrics for weld analysis.





Process Validation

Studies by the Edison Welding Institute have shown the following probability ratio of causes of poor weld quality:

40%	Fixture related
20%	Weld head related
20%	Part/electrode geometry
20%	Weld schedule or power supply related

As with all good manufacturing practices, the welding process must be clearly defined, documented, and validated. The typical steps include:

1. Defining weld quality parameters:
   - Peel, tensile, or shear strength.
   - Part deformation allowable.
   - Nugget penetration and diameter.
   - Cosmetic requirement.
2. Optimizing the weld schedule.
3. Correlating welding and weld monitor with weld quality.
   - Peak weld current and electrode voltage.
   - Displacement (set-down).
   - Force.
   - Nugget diameter (if applicable).
   - Nugget penetration.
   - Peel, tensile or shear strength.
   - Cosmetic acceptability.
4. Establishing process limits.
5. Documenting weld schedule and monitor schedule.
6. Auditing the weld schedule and weld process regularly.
7. Establishing a regular equipment inspection and maintenance.

Weld documentation should address each of the following subjects:

- ***Materials:***
  - ❑ Alloys
  - ❑ Dimensions
  - ❑ Surface Conditions
  - ❑ Projections, if applicable
- ***Power Supply:***
  - ❑ Model/Voltage
  - ❑ Time/Pulse width (msec)
  - ❑ Energy (w-s, I, V, or P)
  - ❑ Heat profile
  - ❑ Limit settings
- ***Weld Transformer:***
  - ❑ Model
  - ❑ Tap Setting
- ***Weld Head:***
  - ❑ Weld head model
  - ❑ Weld force (lbf, Kgf, dN)
  - ❑ Weld cable length
  - ❑ Weld cable diameter
  - ❑ Weld force verification frequency
- ***Electrodes:***
  - ❑ Electrode polarity
  - ❑ Electrode alloys
  - ❑ Electrode dimensions
  - ❑ Electrode gap
  - ❑ Electrode cleaning and changing frequency
- ***Test Parameters:***
  - ❑ Pull strength
  - ❑ Cross section depth
  - ❑ Weld monitor parameters
  - ❑ Sampling schedule
  - ❑ Cosmetic requirements

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MURRAY®

"Tech Tips"

To Murray Customers Only:

Spot Weld Corrosion Resistance vs Sensitization:

Murray is the only US manufacturer that uses spot welding to attach the housing to the band. Over many years our competition has tried to portray this as a negative feature... making claim that welding causes a lower corrosion resistance material. This bulletin will provide the technical aspects with regard to spot welding and corrosion resistance.

In the realm of arc-welding and fabrications that use heavy wall stainless steel pipe and plate... where the material during welding will be in the 800 — 1250 (F) temperature range for an extended period of time... there is a condition created that is called "sensitization". This is a time-temperature transformation of the alloy structure wherein Chromium is pulled out of solid solution and becomes tied up with the element Carbon. The Carbides of Chrome formed in this reaction have a tendency to accumulate (precipitate) at the grain boundaries of the material. These carbides have lower corrosion resistance than the surrounding material... and in corrosive environments... they can lead to a condition known as Stress Corrosion Cracking... which is a corrosive attack of this boundary layer. One industrial practice to combat this condition is to fully anneal the welded areas which dissolves the carbides... and places the chromium back into solid solution. Full corrosion resistance of the material is hence restored.

In material testing labs across the country... where they want to intentionally "sensitize" stainless steel... they will hold a stainless material sample in the 800 — 1250(F) temperature range for 1— 2 hours... followed by a slow air cool. This generates the carbide precipitation at the grain boundaries as described above. The "sensitized" materials are useful in comparing different grades of stainless steel to different environmental (corrosive) conditions. Of great significance here is the amount of time required for this transformation to take place. High temperature must be applied for a long period of time (hours).

In comparison... when Murray spot-welds a housing to a band... there are four (4) spot welds completed in a total of about 0.8 seconds... or 0.2 seconds per weld... including the physical index time. The spot-weld time interval is so short that the stainless does not have adequate time to start making the transformation. Metallographic studies and salt-spray testing have never revealed any "sensitization" or short coming in the corrosion resistance of our spot-welded stainless steel assemblies.

R. Fay
Chief Engineer

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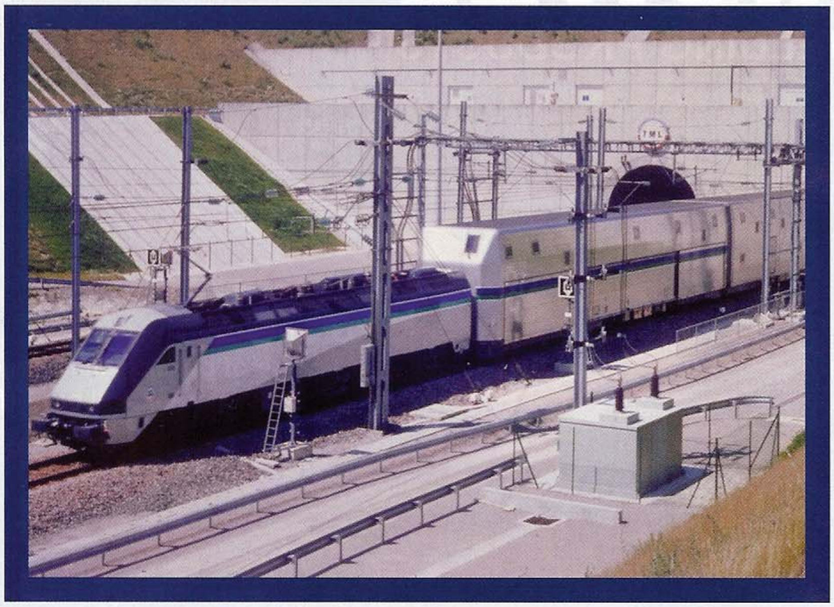
Fabricating Railcars with Resistance Welding



Bombardier Transportation's facility in La Pocatière, Québec, Canada, produced carshells of the Eurotunnel shuttle cars, the largest stainless steel cars ever made. The locomotive is of the standard size. (Photo courtesy of the Nickel Institute.)

An overview is provided on the history, base materials, equipment, and standards regarding the use of resistance welding in creating stainless steel passenger railcars

BY WŁADYSŁAW JAXA-ROŻEN

The application of resistance welding in the production of transportation vehicles has traditionally been associated with automobiles. However, there is a lesser known area where the process has been used with success and to its full potential since the 1930s — fabrication of stainless steel passenger railcars.

History

The use of resistance welding for stainless steel railcar fabrication was a fascinating feat of engineering linked to the creativity and vision of Edward Gowan Budd (1870–1946), founder of the Edward G. Budd Manufacturing Co., Philadelphia, Pa. — Fig. 1. His company was the first to produce all-steel automobile bodies and also one of the first to use resistance spot welding.

During his visit to Europe in 1930, Edward Budd became fascinated with stainless steel. At the same time, Ralph Budd (no relation), president of Burlington Railway, had the idea of applying stainless steel in railway car design and fabrication. Two important developments followed: the mastery of producing 18-8 cold-worked, high-strength austenitic stainless steel by the Allegheny Steel Co., and the growing experience and competence of the Budd Co. regarding formability of the material and spot welding technology.

Stainless steel used by the Budd Co. had tensile strengths up to 160 ksi (1100 MPa) and yield strength of 120 ksi (830 MPa). Its weldability with both fusion and resistance processes was impaired by a relatively high carbon content that caused chromium carbide precipitation in the heat-affected zone (HAZ). Budd's chief engineer, Col. Earl J. W. Ragsdale, found the remedy. His 'shotweld' spot welding process featured a welding time that was shorter than the dwell time causing the development of chromium carbides.

The Creation of Zephyr Trains

As a result, a new kind of passenger rail vehicle was manufactured and put into service in 1934. This was the birth of the Burlington Zephyr trains — Fig. 2. The conjunction of stainless steel, resistance welding, creative minds, and bold management brought a major paradigm shift. Compared with existing railcars, the stainless steel train was much lighter, which in turn made the first application of a diesel-electric propulsion unit practical.

In a display of its speed, the first Zephyr made a 1015-mile nonstop run from Denver to Chicago at the record average of 77 miles/h. Soon after, the first disc brakes were introduced. The sleek sil-

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Based on a paper presented at the AWS Detroit Section's Sheet Metal Welding Conference XIV, Livonia, Mich., May 12–14, 2010.

very train was a forerunner in streamlined industrial design.

The Zephyrs changed railway travel, due to their speed, comfort, and amenities such as attractive interior design, air-conditioning, and an audio system broadcasting radio, public addresses, and music from wire recorders. A popular feature was the domed observation lounge.

Progress

Budd's example was followed by the St. Louis Car Co. and Pullman-Standard in the United States. Together, they produced thousands of stainless steel passenger railcars.

The next important development occurred in Japan, where stainless steel passenger railcars, mostly for subway and commuter trains, have been mass produced since the end of the 1950s. In Asia, stainless steel railcars are also produced in India and South Korea.

In North America, Bombardier Transportation entered the rail transit industry in the mid-1970s and has grown to be a global producer of subway, commuter, and intercity railcars. Its La Pocatière, Québec, facility in Canada has specialized in stainless steel since the beginning of the 1980s. This plant also produced carshells of the Eurotunnel shuttle cars, the largest stainless steel cars ever made — see lead photo. In Europe, for reasons associated with a traditional requirement for car bodies to be entirely painted, stainless steel cars gained only limited popularity. This is not the case in Australia, where stainless steel cars are produced and used.

Materials Used for Railcars Construction

Chemistry

The first stainless steel railcars were made from an austenitic alloy produced by Allegheny and classified by Budd as 18-8 steel consisting of 18% chromium and 8% nickel. Relatively high carbon content made this steel susceptible to chromium carbide precipitation in the HAZ of welds and to subsequent intergranular corrosion. The need to limit dwell time in the critical temperature range inspired the motivation for Budd's experts to invent the short-time spot welding process ('shotweld').

In the 1950s, 201 and 202 steels were also applied. In their chemistries, a substantial part of the nickel is replaced with manganese. Later, 17-7 Type 301 steel was introduced. In the 1980s, the advent of argon-oxygen decarburization allowed the fabrication of low-carbon stainless steels containing less than 0.03% C. This carbon level prevents sensitization of stainless steels caused by welding, either with resistance or fusion processes. Because of recent increases in the price of nickel, the 200 series of stainless steels is currently (2008–2010) regaining interest.

Table 1 — Chemical Composition of Selected Austenitic Stainless Steels

Element	Stainless Steel Grades			
	Allegheny 18-8	304	301L	201L
C	0.12	0.08	0.03	0.03
Cr	17.0, min	18.0 – 20.0	16.0 – 18.0	16.0 – 18.0
Ni	7.0, min	8.0 – 10.5	6.0 – 8.0	3.5 – 5.5
Mn	0.2 – 2.5	2.0	2.0	5.5 – 7.5
Si	0.2–1.5	0.75	1.0	0.75
Cu	0.5	—	—	—
N	—	0.10	0.20	0.25

Contents: wt-%, maximum values unless otherwise specified.

The chemical compositions of selected austenitic stainless steels are presented in Table 1.

With regard to other groups of stainless steels, duplex steels have the potential for application, especially because of their high strength in larger thicknesses. However, they probably will not become popular in the production of railcars. They are more expensive than austenitic steels, and in lower thicknesses (up to about 5 mm), cold-worked austenitics are stronger than duplex steels. Where larger thicknesses are required, high-strength, low-alloy (HSLA) steels with yield strengths up to 700 MPa are commonly used. The use of martensitic and ferritic steels is limited to nonstructural applications.

In the remaining part of this article, only austenitic steels are considered.

Mechanical Properties

In typical descriptions of austenitic stainless steels, their mechanical properties are those in the annealed condition. However, the strength of these materials may be significantly increased by cold deformation, such as thickness reduction in cold rolling, forming, or bending.

Deformation strengthening of austenitic steels results from partial transformation of austenite into martensite. Strength levels of cold-worked stainless steels are covered by ASTM International's A666, *Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar*, and British Standard EN 10088-2, *Stainless Steels: Technical Delivery Conditions for Sheet/Plate and Strip of Corrosion Resisting Steels for General Purposes*.

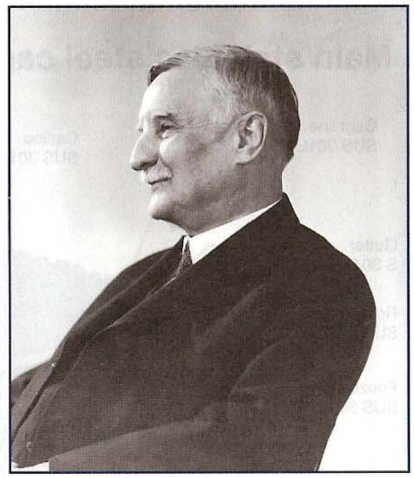

Fig. 1 — Edward Gowan Budd. (Photo courtesy of the Hagley Museum and Library.)

Fig. 2 — The Burlington Zephyr train came into service in 1934. It was a forerunner in streamlined industrial design.

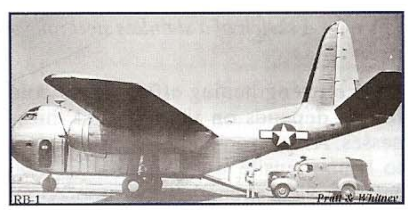

Fig. 3 — Only 20 of the RB-1 Conestoga cargo planes were produced. (Photo courtesy of Wikipedia.)

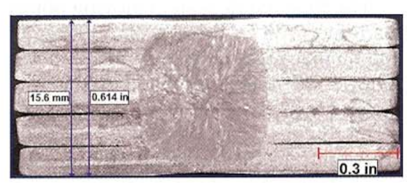

Fig. 4 — A spot weld in a thick assembly, totaling 15.6 mm, is shown. (Photo courtesy of Bombardier.)

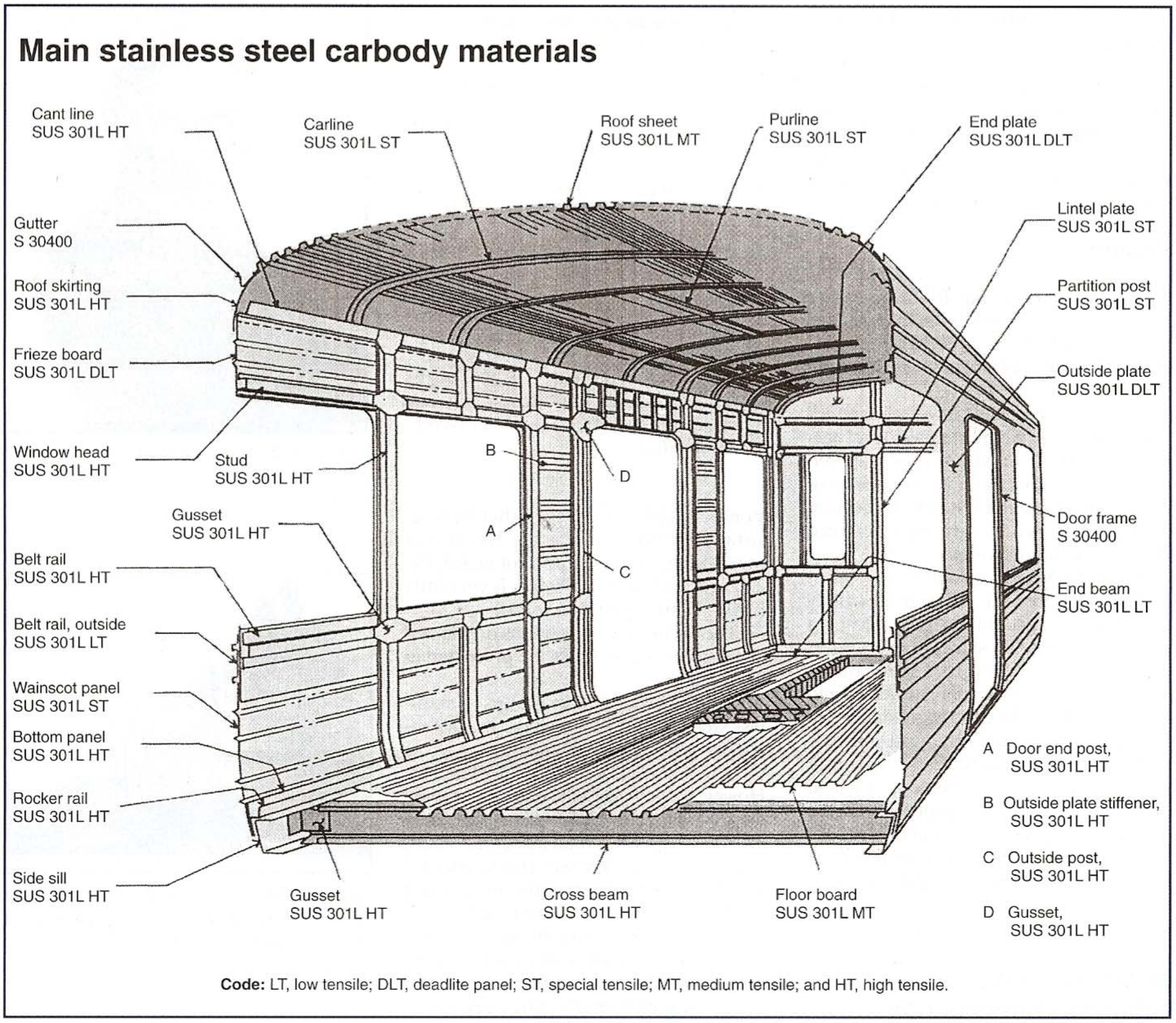

Fig. 5 — A sketch of a stainless steel railcar detailing its key components. (Photo courtesy of the Nickel Institute.)

The strengthening efficiency of cold rolling depends on the material thicknesses. As an example, in thicknesses up to 1 mm, tensile strength close to 1300 MPa and yield strength (0.2% proof) close to 1000 MPa may be achieved. For 5-mm-thick materials, the achievable values are 1000 and 750 MPa, respectively. The high strength-to-weight ratio allows for considering cold-worked stainless steel as lightweight material.

The first stainless steel moving object manufactured by Budd was the Pioneer amphibious plane launched in 1931. It was followed 12 years later by the RB-1 Conestoga cargo plane, 20 of which were built — Fig. 3.

An important characteristic of cold-worked austenitic steels is the absence of yield point in tensile deformation. In design, 0.2% proof stress is typically used as the reference value.

Technological Properties

Austenitic stainless steels can be bent with ease. Even in the cold-worked condition, material may be safely bent with a radius equal to twice its thickness.

Formability of austenitic steels is strongly dependent on the initial condition of the material. Annealed material can be formed without difficulty, while the forming potential of cold-worked materials is limited. If material is to be formed, its final properties resulting from deformation may be considered for design.

Physical Properties

Three properties of austenitic steels are important for resistance welding — electrical resistivity, thermal conductivity, and coefficient of thermal expansion. In comparison with the properties for carbon steels, austenitic steels have a resistivity five times higher, thermal conductivity three times lower, and coefficient of thermal expansion one-third higher.

Weldability

Austenitic stainless steels do not undergo the γ-α transformation, which ensures their good metallurgical weldability. A limited recrystallization occurs in the HAZ, leading to some softening. However, this has practically no consequence on the strength of resistance welds. The HAZ remains ductile in all cases. In either a peel or chisel test of spot welds, a well-defined button is always obtained.

High resistivity of austenitic steels allows for rapid obtaining and growth of the weld nugget. This is further enhanced by the low thermal conductivity, which lim-

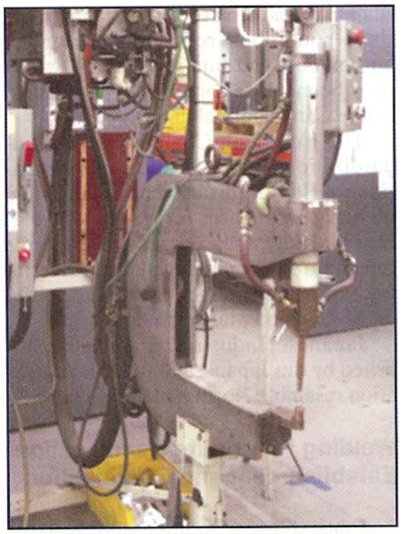

Fig. 6 — A large C-type gun. Welding guns should have a rigid structure, preferably made of a nonmagnetic material. (Photo courtesy of Bombardier.)

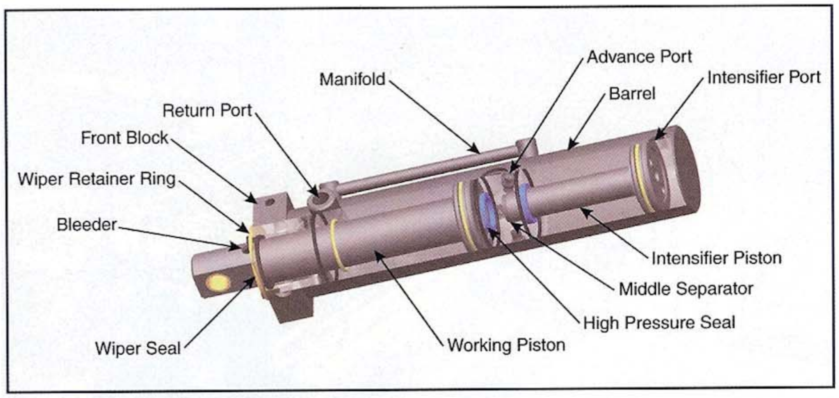

Fig. 7 — An air-over-oil intensifier cylinder is shown. (Photo courtesy of CenterLine Windsor.)

its heat sinking into surrounding material. As a result, relatively low amperages are required, and spot welding multiple part combinations of a large total thickness is possible — Fig. 4.

The high coefficient of thermal expansion results in a tendency to produce nugget shrinkage discontinuities as well as high residual stresses in welds and distortion of assemblies. To prevent both occurrences, high forging forces are applied.

Design

A typical car body is of monocoque design — Fig. 5. The sides and roof consist of cold-formed member frames to which skin is attached. The floor structure is composed of crossbeams, which are fixed to side sills. A center sill is rarely used.

The design strength of spot welds is defined in standards such as the AWS C1.1, *Recommended Practices for Resistance Welding*, and AWS D17.2, *Specification for Resistance Welding for Aerospace Applications*. Minimum distance between spot welds is limited by shunting current. The typical maximum center-to-center distance in North American practice is 50 mm + 2 d, where d represents the nugget diameter. These design principles have ensured structural integrity of the cars through the decades. In addition, the strength of seam welds is comparable to that of base metal and is not a design consideration.

Fabrication

The external surfaces of stainless steel car bodies should be scratch free and flat. No thermal straightening, such as that used in the fabrication of carbon-steel cars, is possible, and restoration of the original finish is difficult. Also, spot weld indentations should be shallow and defect free, and no discoloration on visible surfaces is permitted. The answer to these challenges is the use of protective plastic foil, which is removed just before welding; appropriate welding schedules and sequences; and the use of shielding gas. Contact surfaces of electrodes should be maintained in a perfect state, and the schedules of electrode dressing and replacement should be rigorously respected.

Equipment

General Requirements

Resistance welding equipment should have the following characteristics:

- Large length and width coverage
- High forces up to 20 kN (4500 lbf)
- Moderate amperages with an order maximum of 15 kA for spot welds and 30 kA for seam welds
- High reliability.

A description of the particular equipment elements follows.

Stationary Machines and Mobile Guns

Stationary machines and C-type mobile welding guns should have rigid structures — Fig. 6. Rectilinear movement of electrodes is preferable to rotational movement. For gun structures, nonmagnetic stainless steel is the material of choice.

Cylinders

Cylinders should ensure rapid advance movement, high forces, and soft contact with welded assembly. They should also have a limited size. Hydraulic and pneumatic cylinders only partially meet these requirements. An optimal solution is represented by a cylinder using both media with an internal intensifier. The device makes a quick "soft touch" approach using compressed air. Upon the contact between electrodes and the assembly, the air pressure is converted into a high hydraulic force — Fig. 7. Electric servo-guns represent an interesting application potential, especially when their squeezing force reaches the required level.

Electrodes

Resistance Welding Manufacturing Alliance (RWMA) Class 3 electrodes are used. This class primarily includes UNS C17510 beryllium copper and UNS C18000 nickel-silicon copper, the latter commonly referred to as beryllium-free Class 3. Beryllium copper provides remarkable performance; however, use of this alloy for electrodes has become complicated because of restrictions related to beryllium toxicity. As a result, C18000 is now the preferred alloy for electrodes. A spherical contact surface of a 75 mm (3 in.) radius, recommended by the AWS C1.1 standard, represents an optimal shape. Large electrode diameters around 20 mm (0.750 or 0.875 in.) are preferred.

Gun Positioning

Guns for welding large structures are displaced by gantry systems, the level of mechanization of which varies from manual to fully automatic. In manual mode, spot welds are positioned with the help of templates.

The opposite side of the spectrum is represented by robotic gantry systems, which are typically used for welding side and roof frames. For better flexibility, the welding head is equipped with a gun exchanger.

Welding the roof and side skins to their structures represents a special challenge.

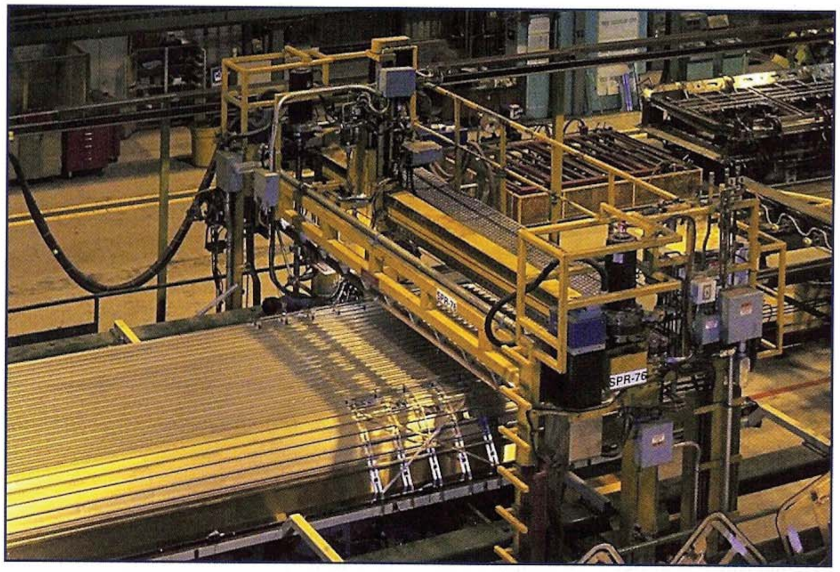

Fig. 8 — *Specialized gantry machines with separate but synchronized mechanical systems for top and bottom electrodes are the solution for welding roof and side skin to their structures. (Photo courtesy of Bombardier.)*

Up to a certain width, mobile C-type guns may be used. In some cases, guns may be introduced through window and door openings. However, this solution is laborious, and not always possible. In the case of roofs, the situation is further complicated by their curvature. A possible solution consists of using specialized gantry machines with separate but synchronized mechanical systems for top and bottom electrodes — Fig. 8.

Power Sources

All kinds of systems may be used to provide welding current. For large spot welding machines, direct current is the preferred logical choice. As in the whole resistance welding industry, medium frequency inverters have made their entrance.

Seam Welding Machines

Seam welding is used to assemble the roof and sometimes the side skin panels. The considerable size of both assemblies requires large installations. Fixed-machine stations have a length that is twice that of a railcar. This is not the case of stations using mobile machines. However, while sparing a lot of floor surface, this solution represents considerable challenges, not least of which is the accurate movement of heavy cantilevered equipment. Weld discoloration is prevented or limited by water jets from the top and bottom sides. The current used is direct with polarity changing from one pulsation to another.

Resistance Welding Controls

Because of the required quality of the welds, as well as of the multitude and complexity of schedules, the most advanced resistance welding controls are sought. Monitoring capability of the controls is used for a signature verification of each weld.

Quality

General Requirements

The requirements for weld integrity and appearance necessitate stringent weld quality criteria. There can be no nugget expulsion. Indentation must be shallow and uniform. Discoloration at surfaces exposed to users is not permitted. There are precise limits of nugget strength, diameter, penetration, and discontinuities.

Standards

The two basic standards used in North America are AWS D17.2, *Specification for Resistance Welding for Aerospace Applications*, which replaced the military specification MIL-W-6858D, *Welding, Resistance: Spot and Seam*, and AWS C1.1, *Recommended Practices for Resistance Welding*. AWS C1.1 covers a larger range of thicknesses, whileAWS D17.2 has requirements for multiple thicknesses.

In Canada, the Canadian Standards Association's W55.3, *Certification of Companies for Resistance Welding of Steel and Aluminum*, is also used. This standard defines conditions regarding personnel, equipment, and quality systems, which must be met by a company to be certified by the Canadian Welding Bureau.

The European Committee for Standardization and International Organization for Standardization have published numerous standards for resistance welding. Typically, they are short documents linked through cross references, describing test procedures, rather than specifying precise acceptance criteria.

Japanese Industrial Standards published by the Japanese Standards Association resemble North American codes.

Welding Procedure Specification Establishment and Qualification

Fabricating car bodies requires a large number of spot welded thickness combinations. Combinations may include three, four, and even five thicknesses of varying gauges. In large stations, dozens of different combinations must be welded, and their number is by far larger than that of available schedules. This represents a challenge for resistance welding technicians. Another difficulty is a need to verify the shear strength qualification assemblies totalling up to four faying surfaces.

Production Control

Every weld is important to the structural integrity of the car. Consequently, rigorous quality control is necessary during fabrication. Monitoring parameters combined with application of threshold values for essential variables allows for real-time verification of the process. On automatic equipment, position and signature records for each weld are used for traceability. Also, frequent testing is performed on samples, namely chisel tests and periodic verification of weld characteristics, which were determined in procedure qualification. The equipment operators' involvement and constant vigilance represent equally important factors in ensuring quality of production welds.

Conclusion

In the fabrication of stainless steel rail cars, resistance welding ensures high-productivity, structural integrity, and aesthetic quality, while taking advantage of the characteristics for austenitic steels.

More than 75 years after introducing resistance welding in passenger railcar fabrication, the legacy of Edward G. Budd and his companions is still alive and well.♦

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Bibliography

Encyclopedia of American Coachbuilders & Coachbuilding. www.coachbuilt.com, www.coachbuilt.com/bui/b/budd/budd.htm.

The ESRC Centre for Business Relationships, Accountability, Sustainability and Society. Cardiff University, UK: Did Ford really invent mass production? *www.brass.cf.ac.uk/uploads/caford PN0603.pdf.*

U.S. Patent 1 944 106. 1934. *Method and product of electric welding*. Earl J. W. Ragsdale (Edward G. Budd Mfg. Co.).

Watter, M. (Edward G. Budd Mfg. Co.) 1940. Stainless Steel in Aircraft, SAE.

Sapp, M. A history of welding. *www.weldinghistory.org, http://weldinghistory.org/whistoryfolder/welding/wh_1900-1950.html.*

PBS. American experience, streamliners, people & events – Edward G. Budd. *www.pbs.org/wgbh/amex/streamliners/peopleevents/p_ebudd.html.*

Wikipedia: Pioneer Zephyr.

Coel, M. 1986. A silver streak, American heritage. Vol. 2, No. 2. *www.americanheritage.com/articles/magazine/it/1986/2/1986_2_10.shtml.*

Reutter, M. 2004. On the wings of the Zephyr, Indiana Historical Society Press. *www.indianahistory.org/ihs_press/web_publications/railroad04/reutter.html.*

Houska, C. 1996. Stainless steel passenger rail cars in North America: 60 years of experience. *International Congress Stainless Steel '96*. Düsseldorf/Neuss.

Hatono, I. 1991. Development of stainless steel railroad cars in Japan. Nickel Development Institute.

Cobb, H. M. 2010. *The History of Stainless Steel*. Materials Park, Ohio: ASM International.

ASTM A666-02, *Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar.*

EN 10088-2:2005, *Stainless Steels: Technical Delivery Conditions for Sheet/Plate and Strip of Corrosion Resisting Steels for General Purposes.*